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CHURCH OPAL EXERCISE (U)

ACODAC MEASUREMENTS (U)

AMBIENT NOISE AND ASSOCIATED PROPAGATION FACTORS AS A FUNCTION OF DEPTH AND WIND SPEED IN THE DEEP OCEAN (U) (PRELIMINARY REPORT)

By

A. F. Wittenborn
Principal Investigator

Prepared for
the

LONG RANGE ACOUSTIC PROPAGATION PROJECT,
NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY

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ACODAC MEASUREMENTS (U)

AMBIENT NOISE AND ASSOCIATED PROPAGATION FACTORS AS A FUNCTION OF DEPTH AND WIND SPEED IN THE DEEP OCEAN (U) (PRELIMINARY REPORT)

(Preliminary Report)

by

A.F. Wittenborn

Principal Investigator

400355

Tracor, Inc.
1601 Research Blvd.
Rockville, Maryland 20850

1 April 1976

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(U) ACKNOWLEDGMENTS (U)

(U) The measurements and analysis discussed in this report are the result of the efforts of a number of people and organizations. The following efforts are acknowledged:

Dr. R. D. Gaul, Manager, LRAPP for giving the program the necessary priority to happen;

Mr. E. L. Smith, ONR Code 102-OSC, CHURCH OPAL Scientific Officer, for integrating the team;

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Dr. Norton Moise, Xonics, Inc., for data analysis planning;

Fleet Numerical Weather Central (FNWC) through Commander Naval Weather Service, for supplying detailed wind, wave, sound velocity and ship traffic reports and predictions;

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Dr. D. T. Mitchell, Texas Instruments, Inc., Unit Investigator ror ACODAC deployment and retrieval;

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Mr. J. Edwards, Texas Instrument, Inc., for supplying a lofargram of one channel of the data tape which served as a valuable road map for data selection;

Dr. A. Anderson, ARL/UTA, through AESD, for supplying propagation loss predictions;

and especially

Mr. J. Shooter, ARL/UTA and his staff, who carried out the data reduction process and contributed significantly to the data analysis effort.

(C) EXECUTIVE SUMMARY (U)

(U) This report presents the results of some measurements of ambient noise and associated propagation factors as a function of depth and of wind speed in the deep ocean. They were part of the CHURCH OPAL Exercise, sponsored by the Long Range Acoustic Propagation Project (LRAPP) of the Naval Ocean Research and Development Activity and conducted during September and October of 1975. The measurements were suggested by some observations of very low noise levels and pronounced depth and wind effects for near bottom hydrophones below critical depth made during the CHURCH ANCHOR Exercise sponsored by LRAPP in the fall of 1973.

(C) The limited observations made during CHURCH ANCHOR were used to formulate a concept called the "noise floor". Some analyses were carried out and a preliminary model for this effect was developed by the Acoustic Environmental Support Detachment (AESD). The noise floor was defined as that depth below which there was a significant decrease in distant traffic noise, produced by bottom interaction and bathymetric shielding, to such an extent that wind dependent noise could become dominant in the frequency region normally dominated by traffic noise. The CHURCH ANCHOR data were limited to frequencies below 250 Hz and, for some of the measurement sites, the hydrophone distribution at depths between critical and the bottom were too sparse to define the depth effect adequately.

(C) The measurements during CHURCH OPAL show that sound from distant sources displays a pronounced depth effect near the bottom over the entire measurement bandwidth from 10 to 500 Hz. "Distant is used for situations where the dominant noise sources are all beyond a range of 150 miles from the receiver. The depth effect observed in these measurements is a decrease in noise level of about 20 dB near the bottom relative to the noise level near critical depth. This decrease in noise level is attributed to

(C)
bottom interaction and compares qualitatively with the results of normal mode calculations of propagation loss over a high loss bottom. Some examples are given where bathymetric shielding contributes significantly to propagation effects related to near bottom hydrophone.

(C) The significant decrease in level for distant source noise due to the depth effect makes it possible to observe directly, with a near bottom hydrophone, the locally generated wind dependent component of the ambient noise over the entire measurement spectrum from 10 to 500 Hz for wind speeds of 15 knots and above. For lower wind speeds the locally generated noise is directly observable only above 150 Hz. As would be expected, the locally generated wind dependent noise displays no depth effect to a first approximation. The observed wind dependent spectral levels as a function of wind speed differ from those inferred by Wenz. The modification of the "Wenz Curves" suggested by these results is shown in figure S-1.

(C) Ship signatures are used to show that no significant depth effect is observable, in the absence of bathymetric shielding, for situations in which the dominant source (or sources) is within about 100 miles of the near bottom receiver. This compares well with the results of normal mode calculations over a lossy bottom. Figure S-2 shows an example of this. The upper curve in the figure shows the ambient spectral levels near critical depth. The spectra represented by the lower curve, for a hydrophone 30 meters off the bottom, are dominated by the signature of a freighter at its closest point of appraoch 100 miles away. Note the presence, in the upper curve, of the line structure displayed in the lower curve, although at a much reduced signal-to-noise ratio.

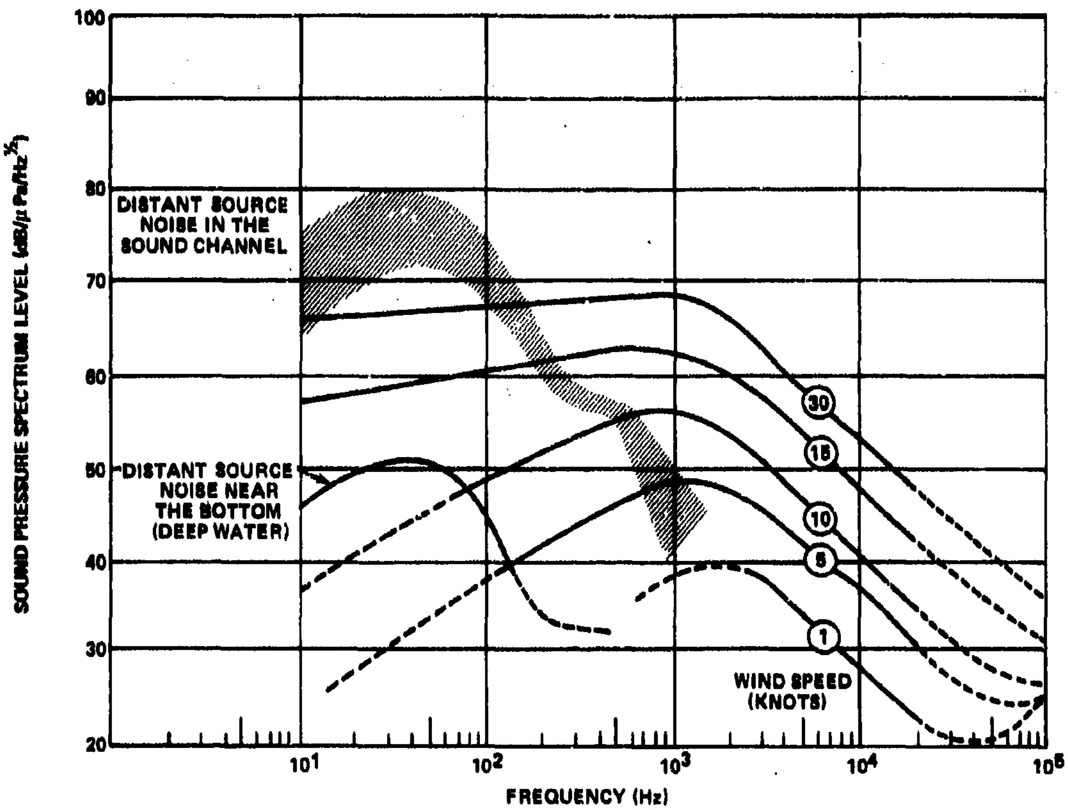

Figure S-1(C). Suggested revision of the "Wenz Curves" for locally generated wind dependent noise between 10 and 500 Hz (U)

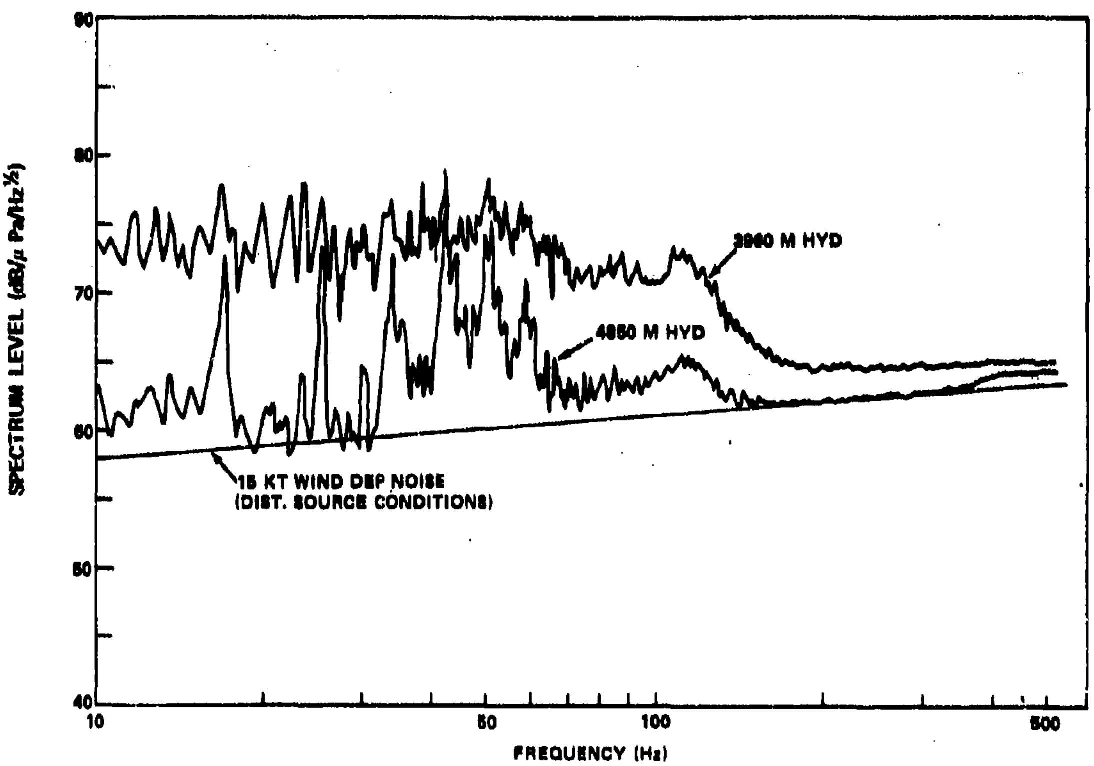

Figure S-2(C). Spectra measured with the 3960 meter (upper curve) and the 4850 meter (lower curve) hydrophones at the closest point of approach of a freighter (German, ADOLF LEONHARDT, bulk carrier, 22,000 tons, 10,600 bhp, 15 knots) 100 miles from the receivers, illustrating the lack of a significant depth effect for a "not distant" source. Local wind speed is 15 knots. (U)

CHURCH OPAL EXERCISE (U)
ACODAC MEASUREMENTS (U)

1.(C) INTRODUCTION (U)

(U) This report presents the results of some measurements of ambient noise and associated propagation factors as a function of depth and of wind speed in the deep ocean. They were part of the CHURCH OPAL Exercise, sponsored by the Long Range Acoustic Propagation Project (LRAPP) of the Naval Ocean Research and Development Activity and conducted during September and October of 1975 (Xonics, 1975). The measurements were suggested by some observations of very low noise levels and pronounced depth and wind effects for near bottom hydrophones below critical depth made during the CHURCH ANCHOR Exercise sponsored by LRAPP in the fall of 1973 (MC Report 108, 1974).

(C) The limited observations made during CHURCH ANCHOR were used to formulate a concept called the "noise floor". Some analyses were carried out and a preliminary model for this effect was developed by the Acoustic Environmental Support Detachment (AESD) (Cavanaugh, 1975). The noise floor was defined as that depth below which there was a significant decrease in distant traffic noise, produced by bottom interaction and bathymetric shielding, to such an extent that wind dependent noise could become dominant in the frequency region normally dominated by traffic noise. The CHURCH ANCHOR data were limited to frequencies below 250 Hz and, for some of the measurement sites, the hydrophone distribution at depths between critical and the bottom were too sparse to define the depth effect adequately.

(U) A number of other measurements have been made of the behavior of ambient noise as a function of depth, frequency and wind speed. A comprehensive discussion of this work, along with extensive references, is given elsewhere (Kibblewhite, et al., 1975; Perrone, 1969 and 1976). Perrone has classified (Perrone,

1975) noise spectra into wind dominated and shipping dominated spectra and has shown that measured noise spectra depends critically on the relative proportions of traffic and wind dependent noise in the measurements area. Locally generated wind dependent noise has a different behavior as a function of depth compared to distantly generated traffic (or possibly even wind dependent) noise. Furthermore, different analysis bandwidths and integration times influence the results, depending on the number and type of noise generating mechanisms included in a sample and the time stationarity of these mechanisms.

(U) The present measurements were made under conditions that have allowed the direct observation, between 10 and 500 Hz, of:

(a) Wind dependent noise spectra, uncontaminated by traffic noise, as a function of depth;

(b) Distant traffic noise spectra, uncontaminated by wind dependent noise, as a function of depth; and

(c) Traffic noise that is local at all depths, where local traffic noise is defined to be noise that is dominated by a single ship source at some depth and below.

Each of these situations leads to different measurement results as a function of depth. The term "noise floor" will, therefore, not be used any further in this report, since the term depth effect, along with the prevailing conditions, is considered more descriptive.

(U) This report has been called preliminary because only about one fifth of the data have been examined. Although it is possible that most of the significant results contained in the data may have been extracted, this is not known to be the case at the present time.

2.(C) THE MEASUREMENTS (U)

(C) The measurements were made during the period 5 September to 16 September 1975 at a site about midway between San Diego and Hawaii (27°40.73'N, 137°55.00'W). Data were recorded on magnetic tape using an Acoustic Data Capsule (ACODAC) configured with a vertical string of 13 hydrophones. The data presented here were taken on eight hydrophones, located in the water column as shown in figure 1.

(U) Wind speed during the deployment period was obtained from Fleet Numerical Weather Central (FNWC), Monterrey, in the form of predictions interpolated to the deployment site at six hour intervals. These predictions were based, in part, on weather reports from ship traffic in the area. Wind speed was also inferred from a continuous record of voltage output of the 4850 meter hydrophone, using a measurement band between 300 and 500 Hz.

(U) Ship traffic was reconstructed from ship position reports supplied by FNWC. Although there is no guarantee that every ship present in the area reported, all ships that can be detected in the data presented here have been identified by type, size and time-track.

(U) A measured speed profile, taken at the time of deployment, is shown in figure 2. Predicted profiles during the deployment period, supplied by FNWC, show little deviation from the measured one.

(U) No data from a calibrated CW source is available for presentation here. Such runs were carried out for other ACODAC deployments during CHURCH OPAL for which the data were not recovered. However, some qualitative aspects of propagation loss are inferred from ship signatures.

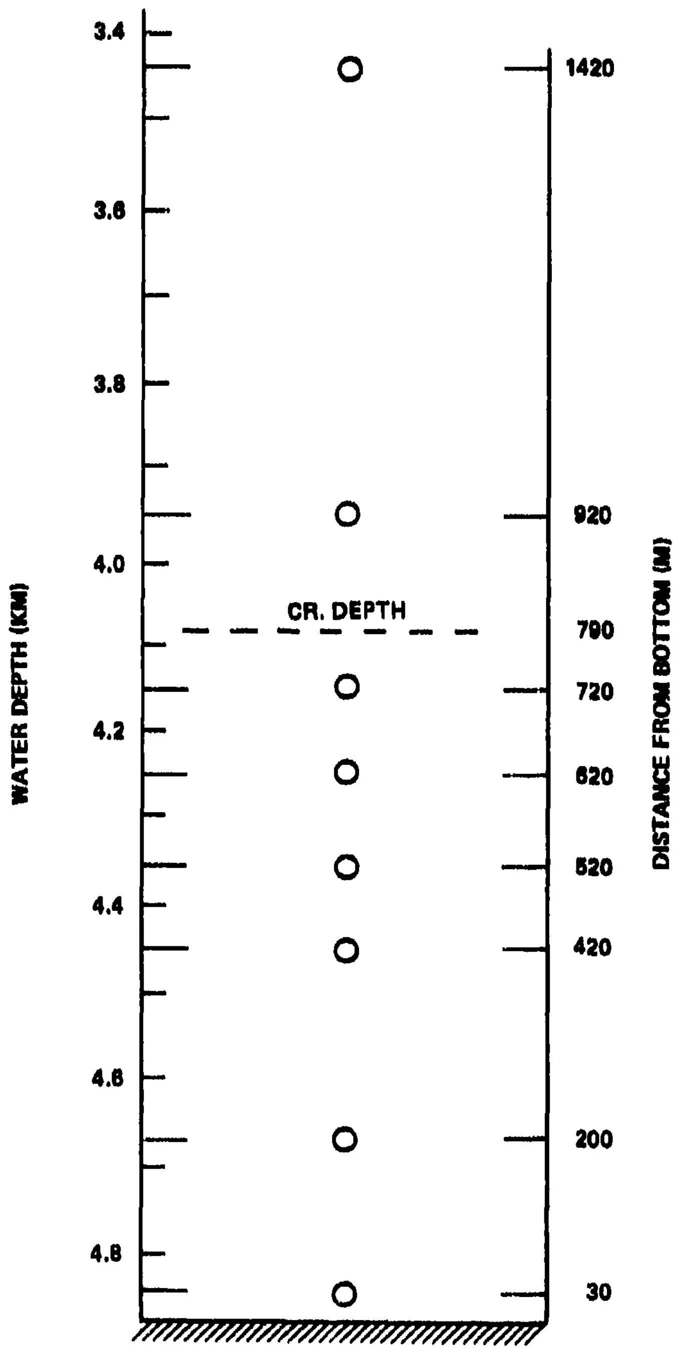

Figure 1(U). Hydrophone locations as a function of depth or distance from the bottom for the CHURCH OPAL data presented in this report (U)

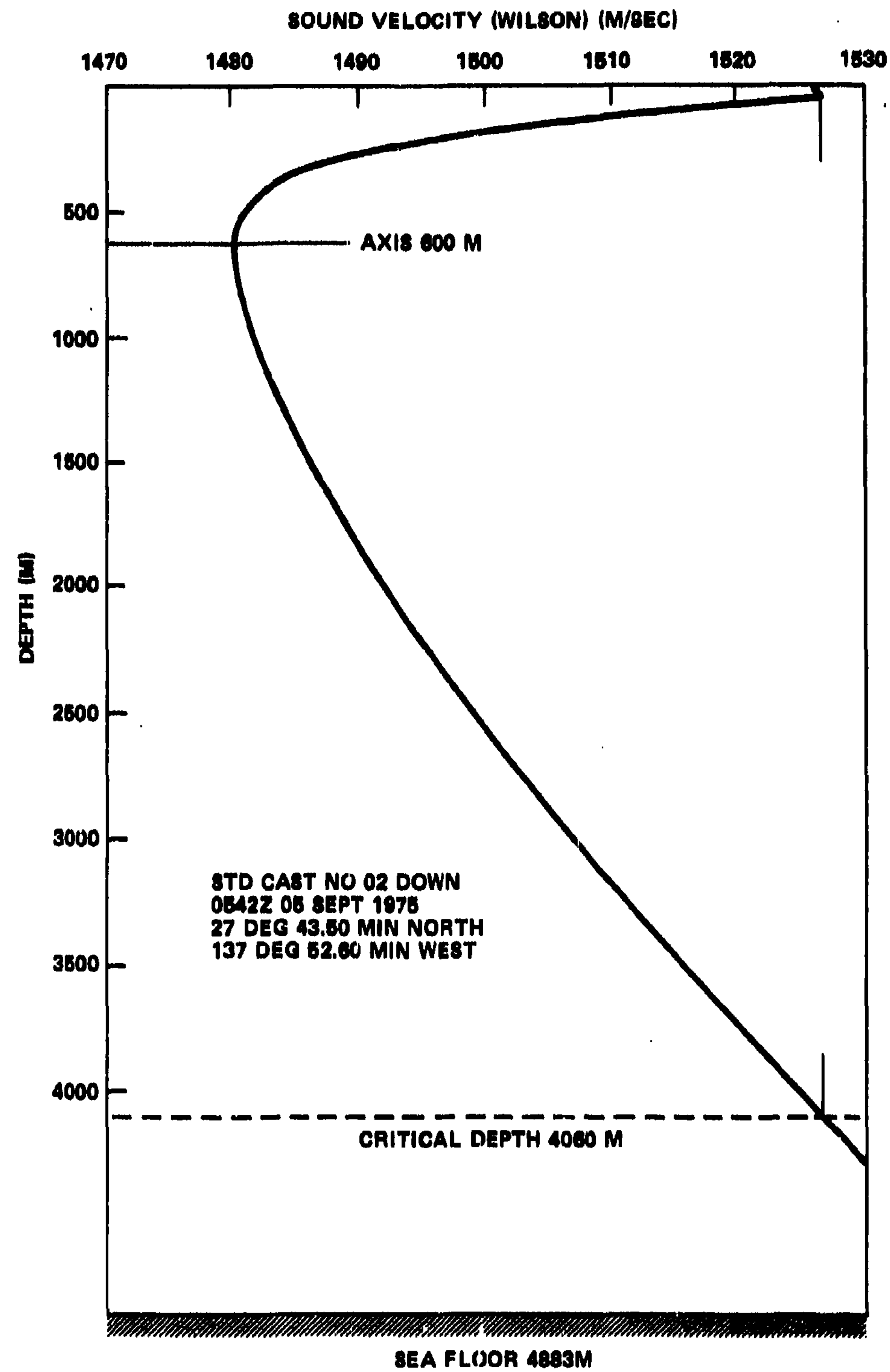

Figure 2(U). Sound speed profile at the measurement site (U)

3.(C) DATA SELECTION AND REDUCTION (U)

(U) In order to avoid the reduction of potentially redundant data, selection was based on obtain data for the number of wind speed categories of nominal values 0, 5, 10, 15, etc., knots occurring during the measurement period. Measurement intervals of several hours duration were considered. From the predictions and the inferred wind speed from the 4850 meter hydrophone, only wind speeds of 15 knots or less actually occurred which were reasonably stable over periods ranging from 12 to 18 hours.

(C) For analyzing ambient noise as a function of depth, the usual "distant shipping" condition is a "baseline" set of spectral levels which are not dominated by a single source, specifically a single ship in the frequency range under consideration here. However, anticipating some of the results to be presented below, two factors arise in this connection which require clarification and comment:

(a) Because the positions (or tracks) of ships which could violate the "distant" criterion are known, it has been possible to quantify the term distant traffic. A single ship dominates the spectra to a range of 30 to 40 miles for a hydrophone in the sound channel. Because of the observed depth effect, for a near bottom hydrophone a single ship totally dominates the noise spectra to a range of 100 miles and is completely merged into the ambient background at a range of about 150 miles. Therefore, "distant shipping" is defined as a situation where no single ship dominates the spectra (i.e., there is no recognizable or dominant line structure present in the data) from the near bottom

(C)

hydrophone. This implies that there is no ship closer than about 150 miles. For the actual noise samples given below, the closest ship is at a range of 175 miles, with the majority of the ships more than 250 miles away.

(b) The spectra observed between 200 and 500 Hz for the "distant shipping" condition and low wind speeds do not exhibit the rapid fall-off with frequency that is usually assigned to "distant shipping". This same behavior can be seen in data taken off Bermuda (Perrone, 1969) at very low wind speeds. It is possible, in the present context of defining "distant", that the observed spectra under "distant shipping" and low wind speed (local) conditions are the result of a combination of "distant shipping" and "distantly generated" wind dependent noise. Although methods are available for examining this further (e.g., Perrone, 1975) the matter will not be considered further in this report. Instead, the term "distant source" or occasionally "distantly generated" noise will be used instead of "distant shipping". Correspondingly, noise that is produced by local winds will be called "local source" or "locally generated" noise.

(U) The basic approach to data reduction was to obtain reliable "snapshots" of the ambient noise fields and of ship signatures when present. In order to understand or unravel the individual components of ambient noise, data reduction and analysis must be carried out with a frequency resolution sufficiently

(U)

fine to identify the characteristics of the generators of the noise field and with an integration time short enough to guarantee that the collection of generators has not changed significantly during the integration period. (c.f. Wagstaff, 1975.)

(C) In this connection, figures 3 and 4 show a 6 hour sample, at selected frequencies, of ambient noise as a function of time for a 2 minute and a 10 minute integration time at a wind speed of 5 knots. The curves are displaced relative to each other by the number of dB indicated to the far left of each curve on the figures. From the figures it can be seen that either the 2 minute or the 10 minute integration time could be suitable for a snapshot analysis. On the other hand, the areas of seismic activity, displayed below 40 Hz, at 1630 hours, as well as the change in wind speed indicated by the frequencies above 300 Hz between 1400 and 1600 hours are to be avoided. A different 6 hour sample is shown in figure 5 for an integration time of 10 minutes at a wind speed of 5 knots. Here conditions are somewhat more stable. Three 6 hour samples of data, in the format of figures 3, 4, and 5 were examined for each of the three wind speeds to select representative "snapshots".

(U) The results presented here consist of the following types of samples:

Ambient noise - 0.2 Hz frequency resolution, 10 minute integration time, 10 to 500 Hz; and

Ship signatures - 0.1 Hz frequency resolution, 10 minute integration time, 10 to 500 Hz.

The machine processed output has the form shown in figure 6. The upper curve resulted from a 12,000 ton Japanese freighter passing directly over the receiving hydrophones. The lower curve is a sample of ambient noise for a 5 knot wind speed and distant source conditions as defined above. The figure could well be entitled "The extremes of the events of a day in the life of a near bottom hydrophone."

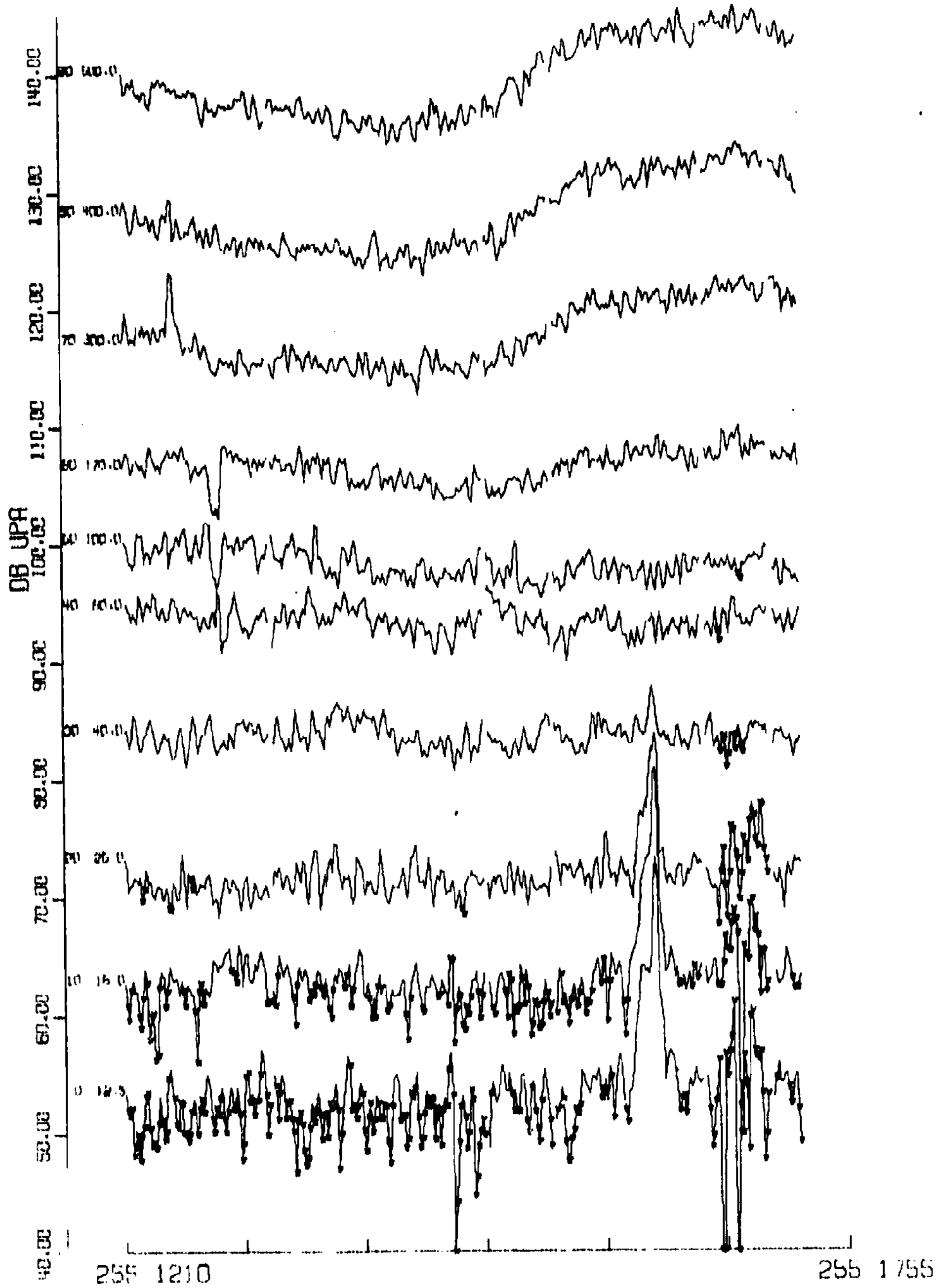

Figure 3(C). Ambient noise levels as a function of time for the indicated frequencies, using a two minute integration time, for Julian Day 255 from 1210 to 1755 hours. (The number to the far left of each curve indicates the number of dB the curve is displaced relative to the ordinate scale.) (U)

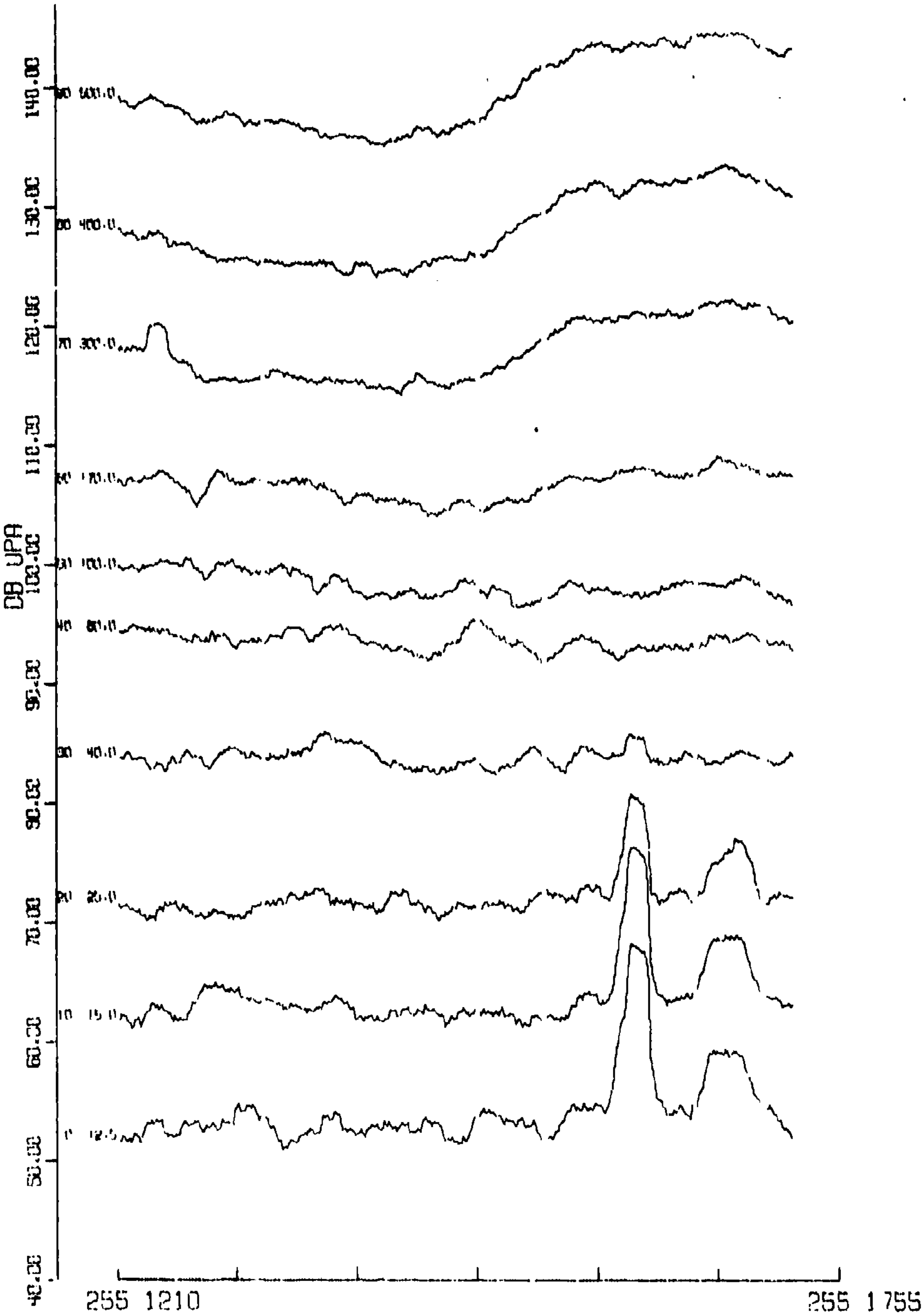

Figure 4(C). Ambient noise levels as a function of time for the indicated frequencies, using a 10 minute integration time, for Julian Day 255 from 1210 to 1755 hours. (The number to the far left of each curve indicates the number of dB the curve is displaced relative to the ordinate scale.) (U)

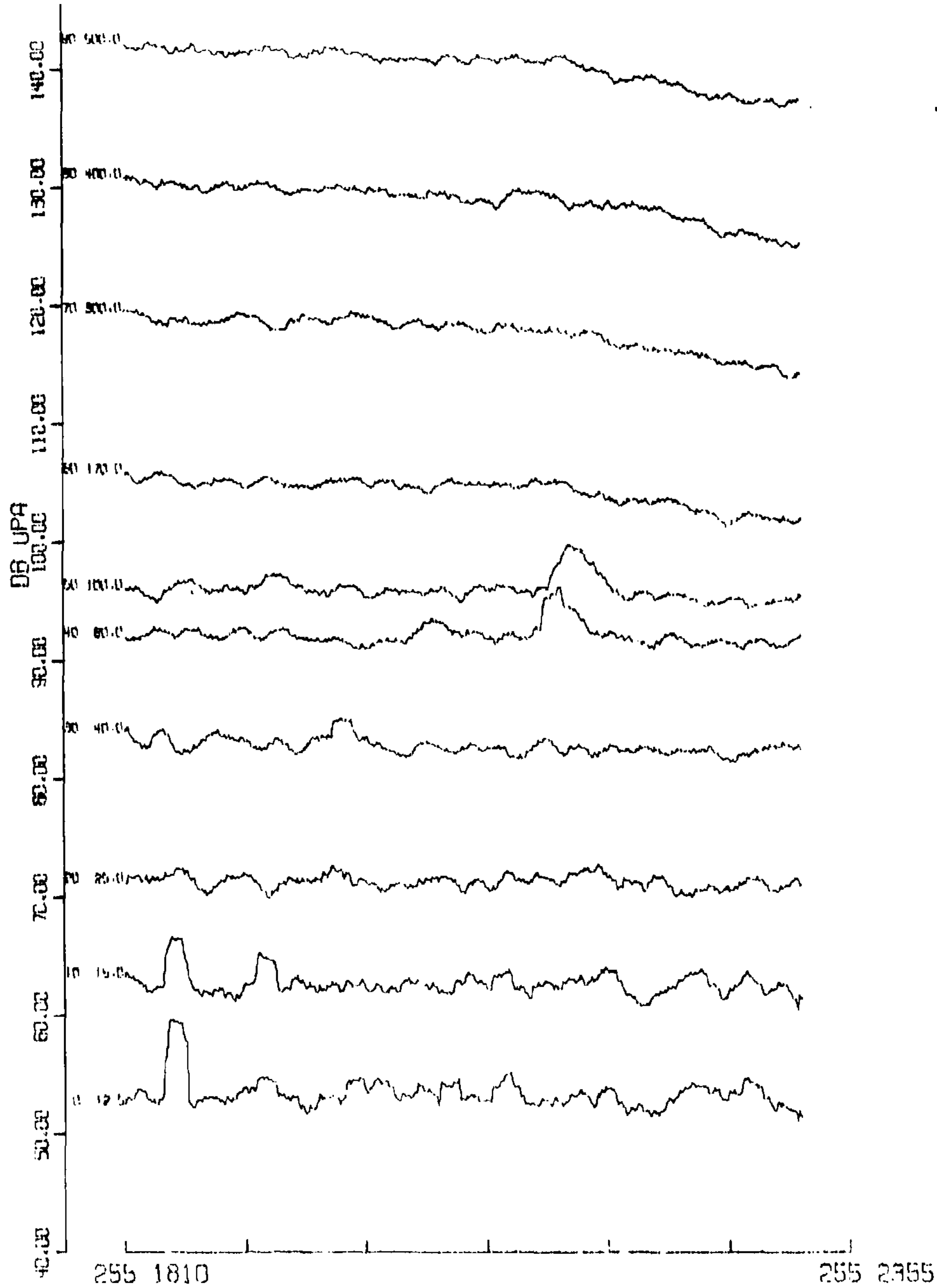

Figure 5(C). Ambient noise levels as a function of time for the indicated frequencies, using a 10 minute integration time, for Julian Day 255 from 1810 to 2355 hours. (The number to the far left of each curve indicates the number of dB the curve is displaced relative to the ordinate scale.) (U)

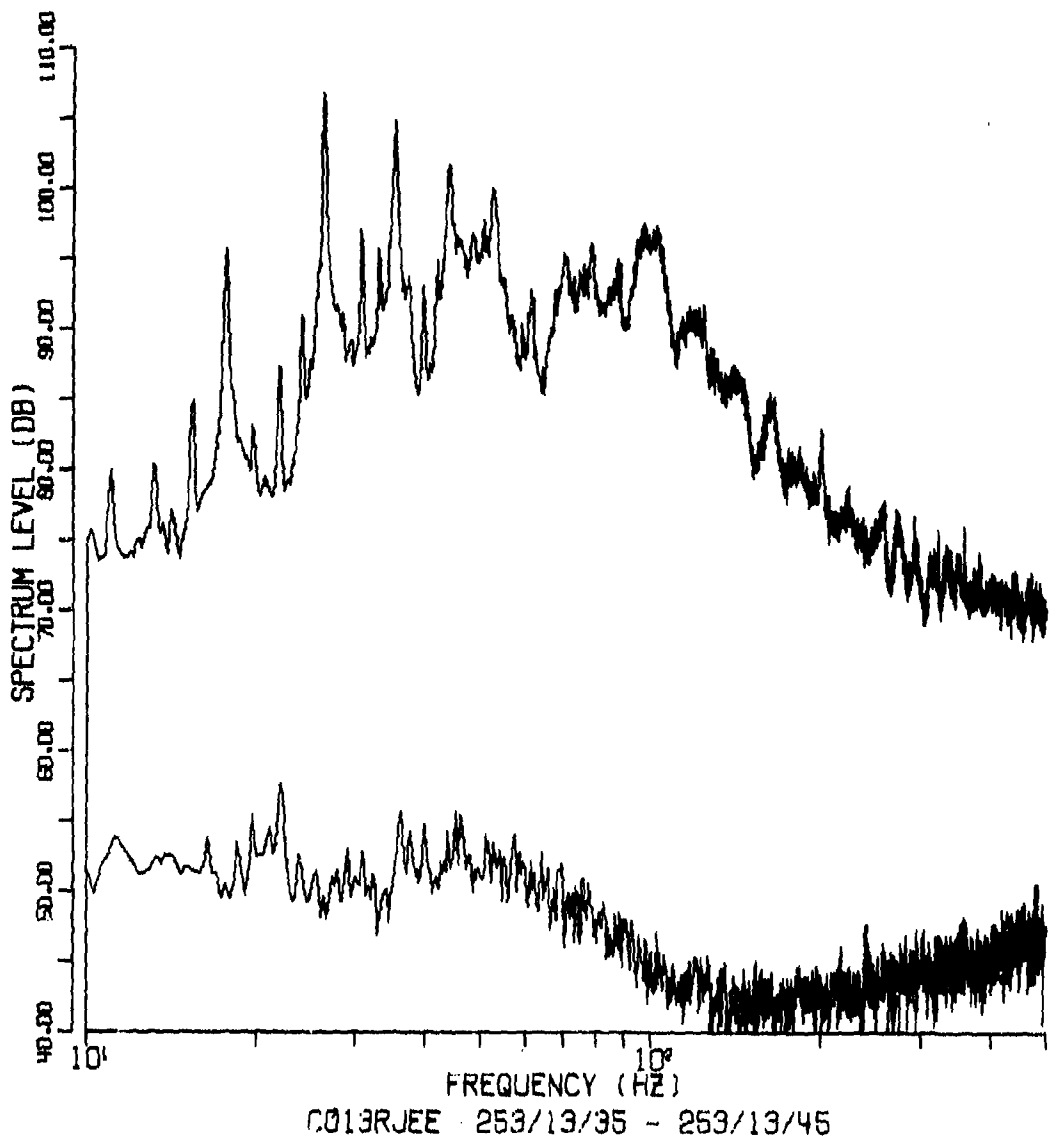

Figure 6(C). Two examples of processed spectra as measured with the 4850 meter hydrophone. The upper curve corresponds to the CPA of a freighter passing overhead, 0.1 Hz frequency resolution 10 minute integration time. The lower curve corresponds to distant shipping (as defined in the text), 5 knot wind speed, 0.2 Hz frequency resolution, 10 minute integration time (U)

(U) In the folloiwng sections, most of the results will not be presented in the format of figure 6, due to graphics difficulties in producing multiple curves on a single figure. Instead, the machine processed spectra will usually be represented as a line through the median of the excursions.

4.(C) RESULTS AND DISCUSSION (U)

4.1(C) Ambient Noise Data (U)

(U) Representative ambient noise spectra for wind speeds of 5, 10 and 15 knots and distant source conditions as defined above are shown as a function of hydrophone depth in figures 7, 8 and 9. The numbers on the curves correspond to the hydrophone depth indicated on the legend.

(C) One noticable feature is the behavior of curve 6 in Figures 7, 8, and 9. This has been examined in some detail, and, although the recording equipment was not available for post measurement calibration, the behavior is considered to be real. A similar behavior is exhibited by some of the CHURCH ANCHOR data (Kibblewhite, 1976) as well as by normal mode calculations of propagation loss (Pederson, 1976). The effect is attributed to certain "mode interactions" or "mode focusing" and remains to be explored in further detail. This is considered beyond the scope of this report, so that the behavior of curve 6 will be ignored in the subsequent discussion.

(C) From figure 7, in the frequency region between 10 and 100 Hz, the curves show essentially a monotonic decrease in level with depth. The noise in this frequency region is normally considered to be caused by ship traffic. The set of spectral levels vs. depth at, say, 50 Hz thus represents the variation of distantly <u>generated</u> noise with depth.

(C) The spectra between 200 and 500 Hz show a change in shape between curves 2 to 6 and curves 7 and 8. This change is attributed to a transition from distantly generated noise on the upper hydrophones to locally generated (wind dependent) noise on the deepest hydrophone. As the level of distantly generated noise decreases with depth, as is indicated at 50 Hz, a point is reached at which the locally generated noise becomes dominant. The set of spectral levels vs. depth at, say, 300 Hz thus

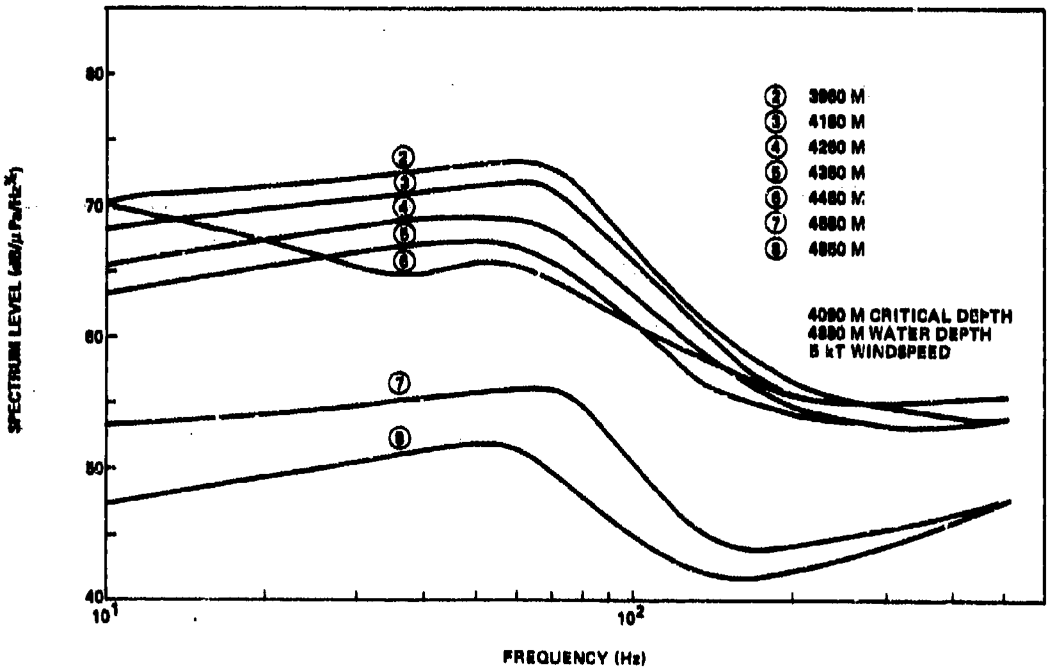

Figure 7(C). Representative ambient noise spectra for a 5 knot wind speed and distant source conditions for the indicated hydrophone depth (0.2 Hz frequency resolution, 10 minute integration time.) (U)

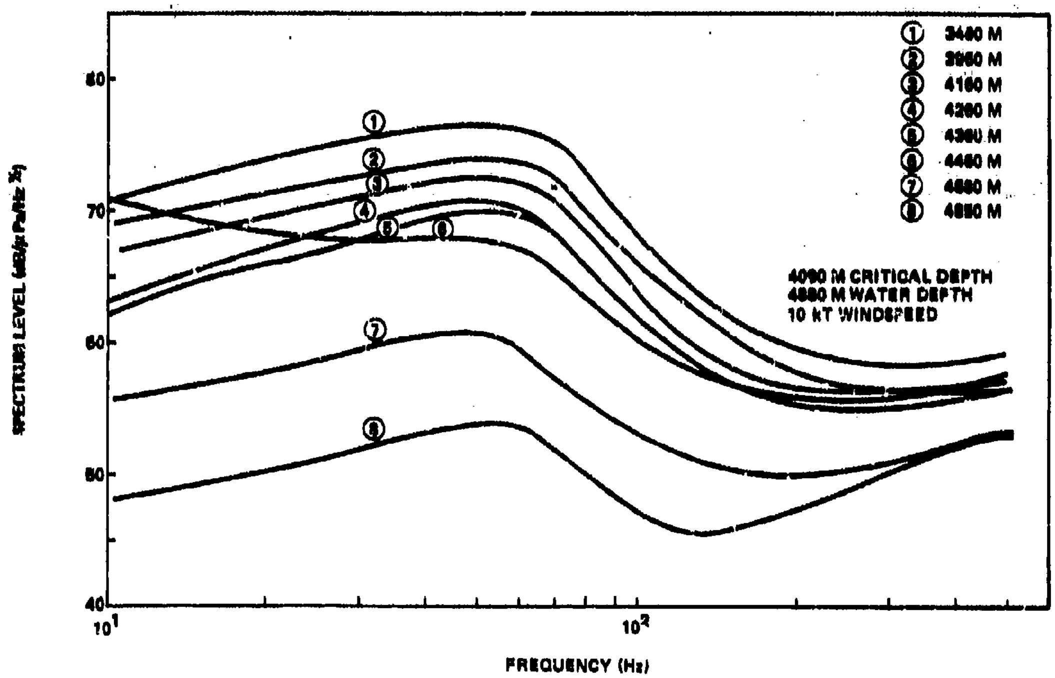

Figure 8(C). Representative ambient noise spectra for a 10 knot wind speed and distant source conditions for the indicated hydrophone depths (0.2 Hz frequency resolution, 10 minute integration time.) (U)

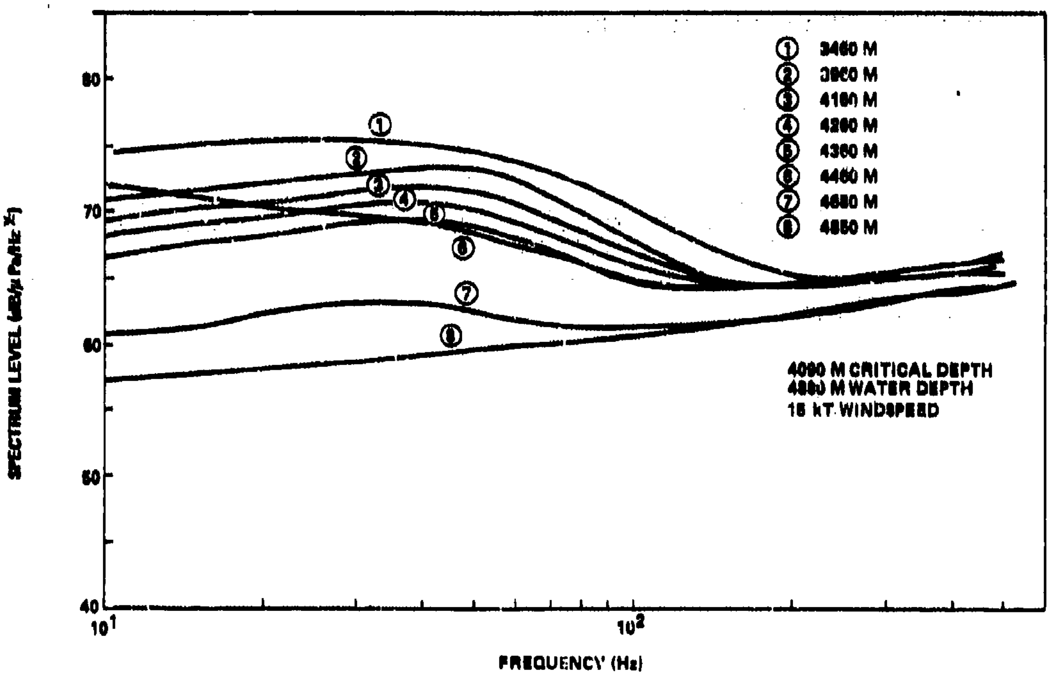

Figure 9(C). Representative ambient noise spectra for a 15 knot wind speed and distant source conditions for the indicated hydrophone depths (0.2 Hz frequency resolution, 10 minute integration time.) (U)

(C)

represents a transition from distantly generated noise to locally generated noise.

(C) A similar situation is shown in figure 8 for a 10 knot wind speed and distant source conditions. The spectral levels between 10 and 100 Hz decrease monotonically with depth and are dominated by distantly generated noise. Between 200 and 500 Hz, the change in spectral shape again suggests the transition from distantly generated noise domination on the upper hydrophones to locally generated noise domination on the lowest hydrophone. Here, again, the set of spectral levels vs. depth at 50 Hz represents the variation of distantly generated noise with depth and, as such, insofar as the traffic noise levels are the same as for the 5 knot wind speed data, should show the same variation with depth as the 5 knot wind speed data. The set of spectral levels vs. depth at 300 Hz represents a transition from distantly generated noise to locally generated noise, and insofar as the traffic noise levels are the same as for the 5 knot wind speed data, should show the same variation with depth as the 5 knot wind speed data until the locally generated noise becomes dominant.

(C) A quite different situation occurs for a wind speed of 15 knots, as is shown in figure 9. Note here that the monotonic decrease in level as a function of depth at 50 Hz is interrupted for the lowest hydrophone output relative to the values given on figures 8 and 9 for this hydrophone at the lower wind speeds. The interruption is caused by a transition from distantly generated noise domination to locally generated noise domination. At 300 Hz, on the other hand, the variation of spectral level with depth has virtually disappeared. This indicates that the spectral levels are dominated by locally generated noise throughout the water column. The set of spectral levels vs. depth at 50 Hz thus represents a transition from distantly generated noise on the upper hydrophones to locally generated noise on the lowest hydrophone. The set of spectral levels vs. depth at 300 Hz represents

(C)
locally generated noise throughout the water column and, as such, should display no variation with depth to a first approximation. (Urick, 1975; Perrone, 1975.)

(C) Another way to look at the effect of depth and wind speed is shown in figure 10, which gives the spectral levels at the three wind speeds for the 3960 meter (just above critical depth) and the 4850 meter (30 meters off the bottom) hydrophones. At 50 Hz the curves labelled (1) from the upper hydrophone show approximately equal levels of distantly generated (traffic) noise in the sound channel for the three wind speeds. The curves labelled (2) from the lower hydrophone show the reduced distantly generated noise for 5 and 10 knot wind speeds and a higher wind dependent level for the 15 knot wind speed. Thus, pure distant source noise as a function of depth is obtained for 10 knot wind speeds and below. At 300 Hz the upper hydrophone shows a decrease in spectral level with diminishing wind speed. Comparison with the lower hydrophone spectral levels shows that the wind dependent level at 5 knots wind speed is sufficiently low that the curve for the 5 knot wind speed for the upper phone is pure distant source dominated to 500 Hz, essentially uncontaminated by wind generated noise. (There is a slight contamination of the 10 knot curve, while 15 knots is wind dominated.) The spectral shape of distant source noise for the 5 knot wind speed does not have the rapid fall-off above 100 Hz that is usually assigned to distant shipping. Instead, the spectral shape exhibits a "plateau" between 200 and 500 Hz. This shape is also evident in the spectra measured by Perrone (1969), as will be seen later. The plateau could be caused by distantly generated wind noise. Until this question is resolved, it is felt that the wording, distant source, or distantly generated noise, needs to be retained.

(C) Figure 11 shows a sample of ambient noise data, processed in the same way as the data above, for a wind speed of 30 knots recorded during CHURCH ANCHOR. The hydrophone depths,

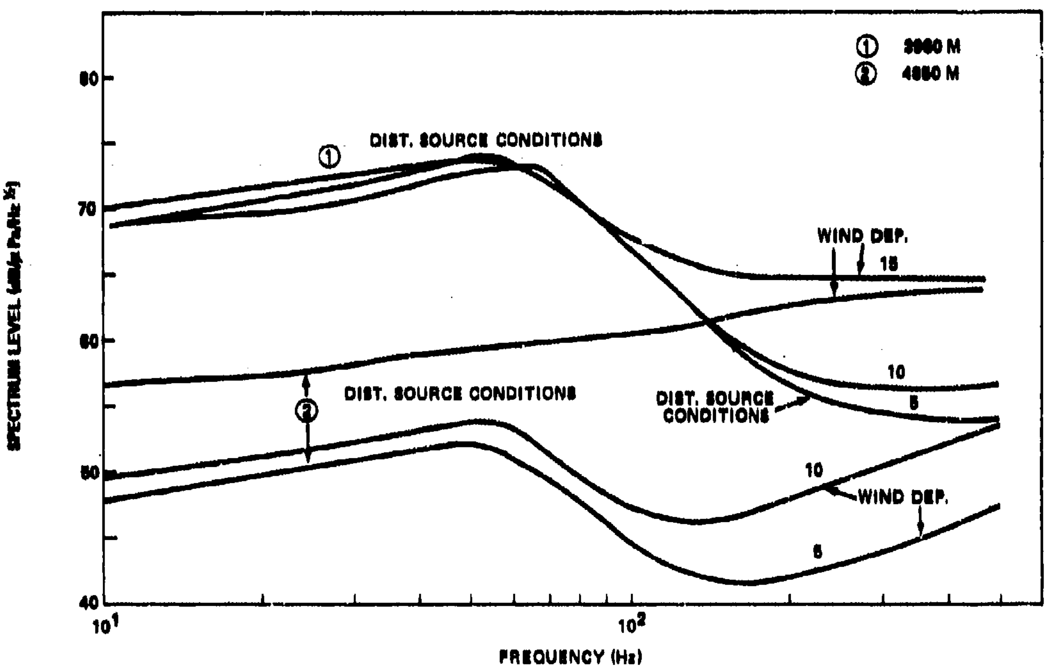

Figure 10(C). Representative ambient noise spectra as measured on the 3960 meter and the 4850 meter hydrophones for wind speeds of 5, 10, and 15 knots (0.2 Hz frequency resolution, 10 minute integration time.) (U)

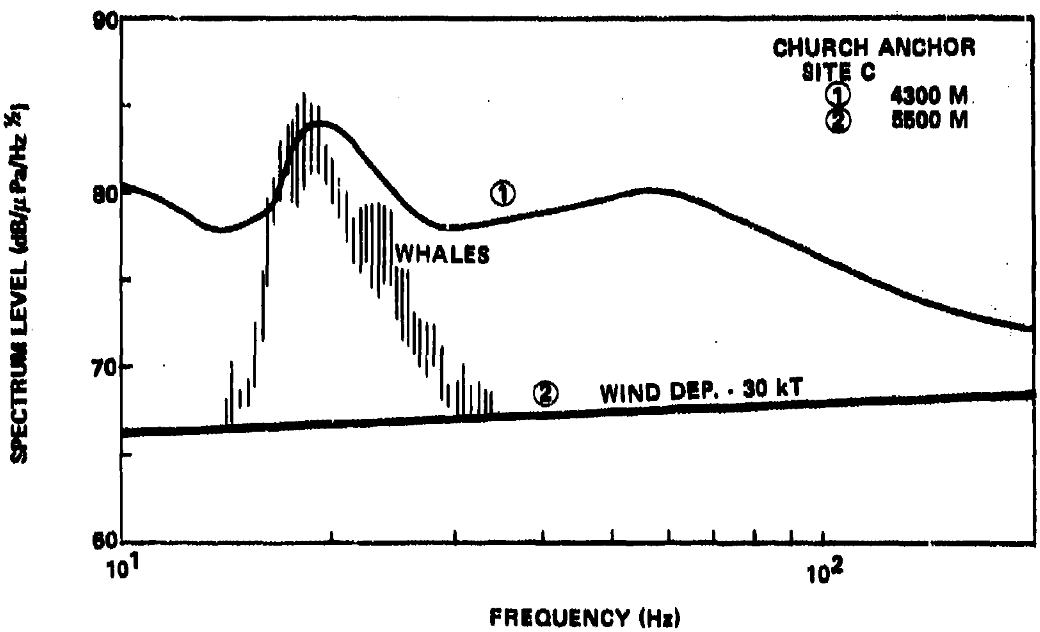

Figure 11(C). Representative ambient noise spectra as measured during CHURCH ANCHOR on a 4300 meter and a 5500 meter hydrophone for a wind speed of 30 knots (0.2 Hz frequency resolution, 10 minute integration time) (U)

(C)

shown on the figure, are of approximately the same separation as those for figure 10. The lower curve is dominated by wind dependent noise while the upper curve is dominated by traffic noise. The level of traffic noise for this location is evidently somewhat higher than it is for the CHURCH OPAL site. The high levels near 20 Hz are due to whales and consist of a large number of nominal 20 Hz bursts about 20 cycles long.

(C) It was pointed out in Section 3 that wind speed was obtained from FNWC predictions and checked, qualitatively, by using the output from the near bottom hydrophone between 300 and 500 Hz. As further "calibration" of the wind speed, the spectra have been compared to those observed during CAPER (Morris, 1976) and those obtained off Bermuda (Perrone, 1969). Figure 12 shows the comparison with Perrone's data, for which wind speed was measured with an anemometer 30 miles from the measurement site. The merging of the two sets of measurements for the 15 and 30 knot wind speeds is considered good. Because of the very rapid change in the level of the locally generated wind dependent noise from 0 to 15 knots observed here, and the lack of other observations, further quantitative measurements would certainly be useful in order to quantify the noise levels as a function of wind speed more accurately.

4.2(C) Local Wind Dependent Ambient Noise (U)

(C) From the preceeding discussion, it will be recalled that locally generated noise, uncontaminated by distantly generated noise, was observed throughout the water column at 300 Hz for a wind speed of 15 knots. The behavior with depth at 300 Hz for this wind speed, as well as for the 5 and 10 knot wind speeds, is shown in figure 13. For this situation of distributed sources at the surface, above the receivers, no significant depth effect would be expected (c.f. e.g., Urick, 1975; Perrone, 1975). A small effect would be expected below critical depth because of the exclusion of noise from surface sources for which the refracted rays do not reach the near bottom hydrophones.

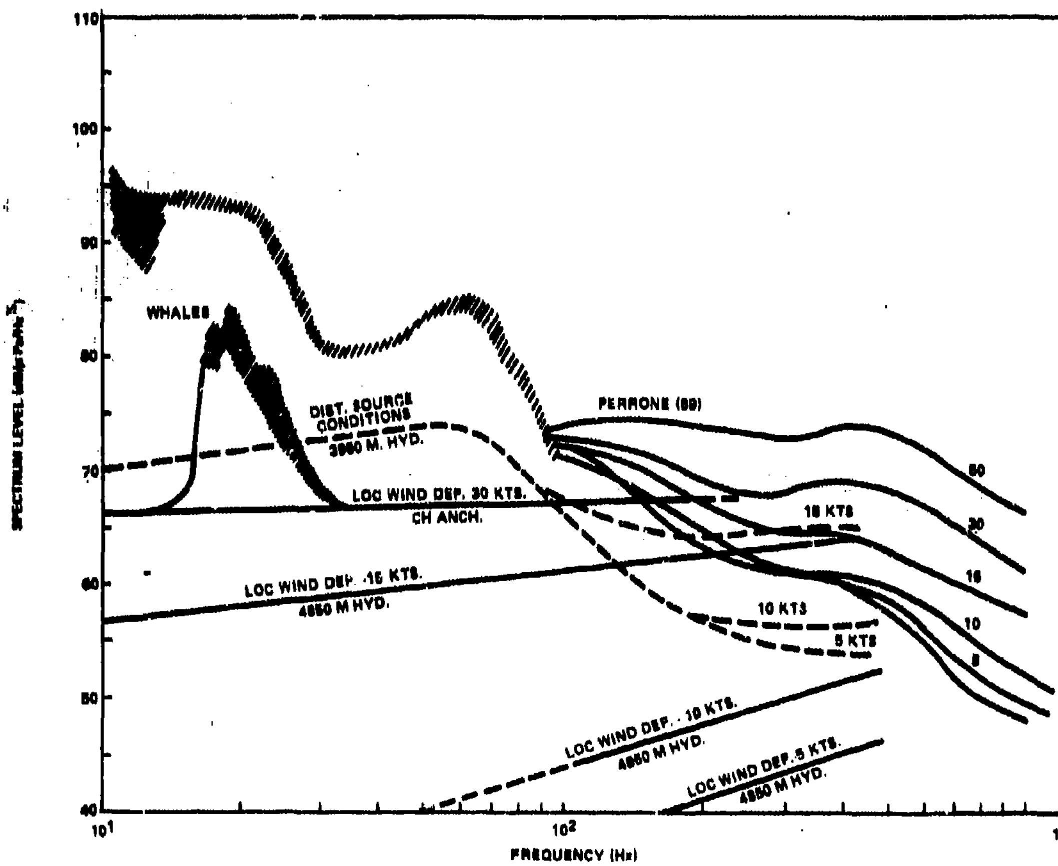

Figure 12(C). The present results compared to those of Perrone (1969) for "calibration" (U)

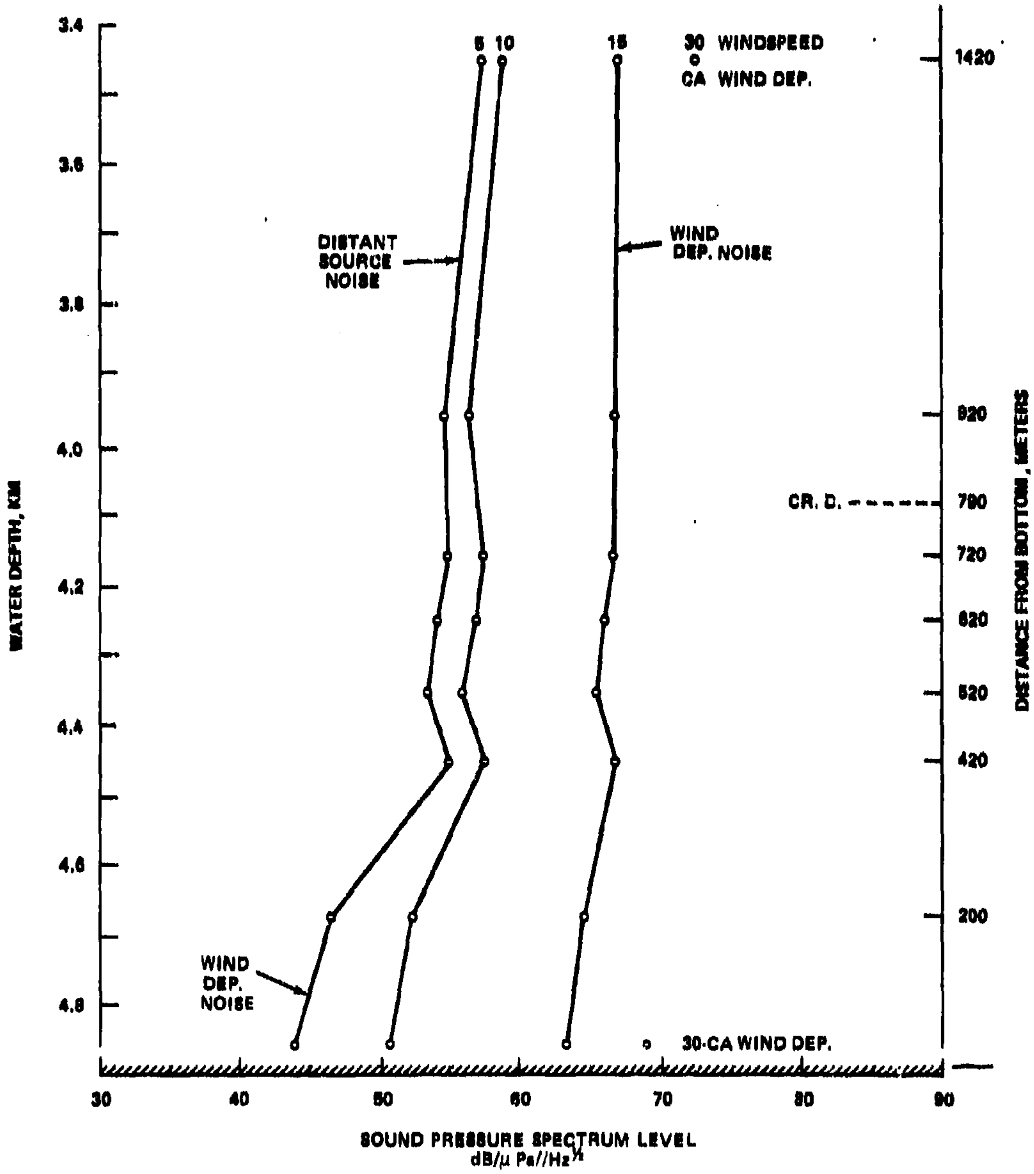

Figure 13(C). Ambient noise levels as a function of depth at 300 Hz for wind speeds of 5, 10, and 15 knots. (The points labelled CA correspond to a wind speed of 30 knots, as measured in CHURCH ANCHOR.) (U)

(C) Keeping in mind that the noise levels for lower wind speeds are subject to some quantitative adjustment, a modification to the wind dependent spectra between 10 and 500 Hz originally inferred by Wenz (1962) is suggested by these results. This is shown in figure 14. No extrapolation is inferred below 10 Hz. A number of measurements (e.g. Perrone, 1970) have shown a different wind dependence in the region of 10 Hz than that observed here. The dependence on location at the low frequency end remains to be resolved.

4.3(C) Propagation Effects (U)

(C) As discussed previously, distant source noise, uncontaminated by locally generated wind dependent noise, was observed throughout the water column at 50 Hz for wind speeds below 10 knots. The behavior with depth at 50 Hz is shown in figure 15 for 5, 10 and 15 knot wind speeds. The 15 knot curve shows less variation in level with depth near the bottom than the 5 and 10 knot curves because the locally generated wind noise level at 15 knots exceeds the distant source noise level.

(C) The ability to make the distinction between uncontaminated distant source noise as a function of depth and a depth dependence which is produced by a mixture of distant source and locally generated noise is, of course, of great importance to ambient noise modeling. While locally generated wind dependent noise can readily be "modeled" empirically from good quantitative data of the type shown in figure 14, the modeling of the distant source depth effect depends on modeling near bottom propagation. The following discussion consists of a number of observations with respect to the distant source depth effect based on the present data.

(C) An example of the results of a calculation using normal mode theory (Gordon, 1975) of propagation loss as a function of depth with source range as a parameter for environmental conditions typical of the Northeast Pacific is reproduced in figure 16. Note that these calculated results suggest that a significant depth

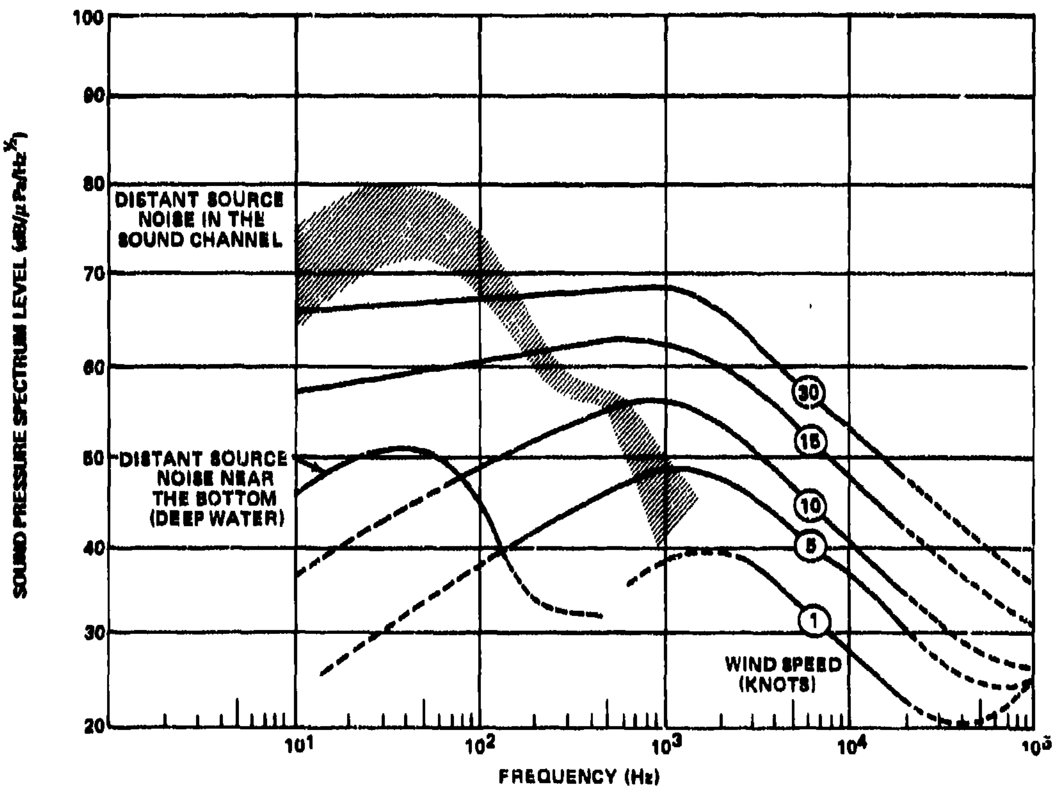

Figure 14(C). Suggested revision of the "Wenz" (1962) curves between 10 and 500 Hz (U)

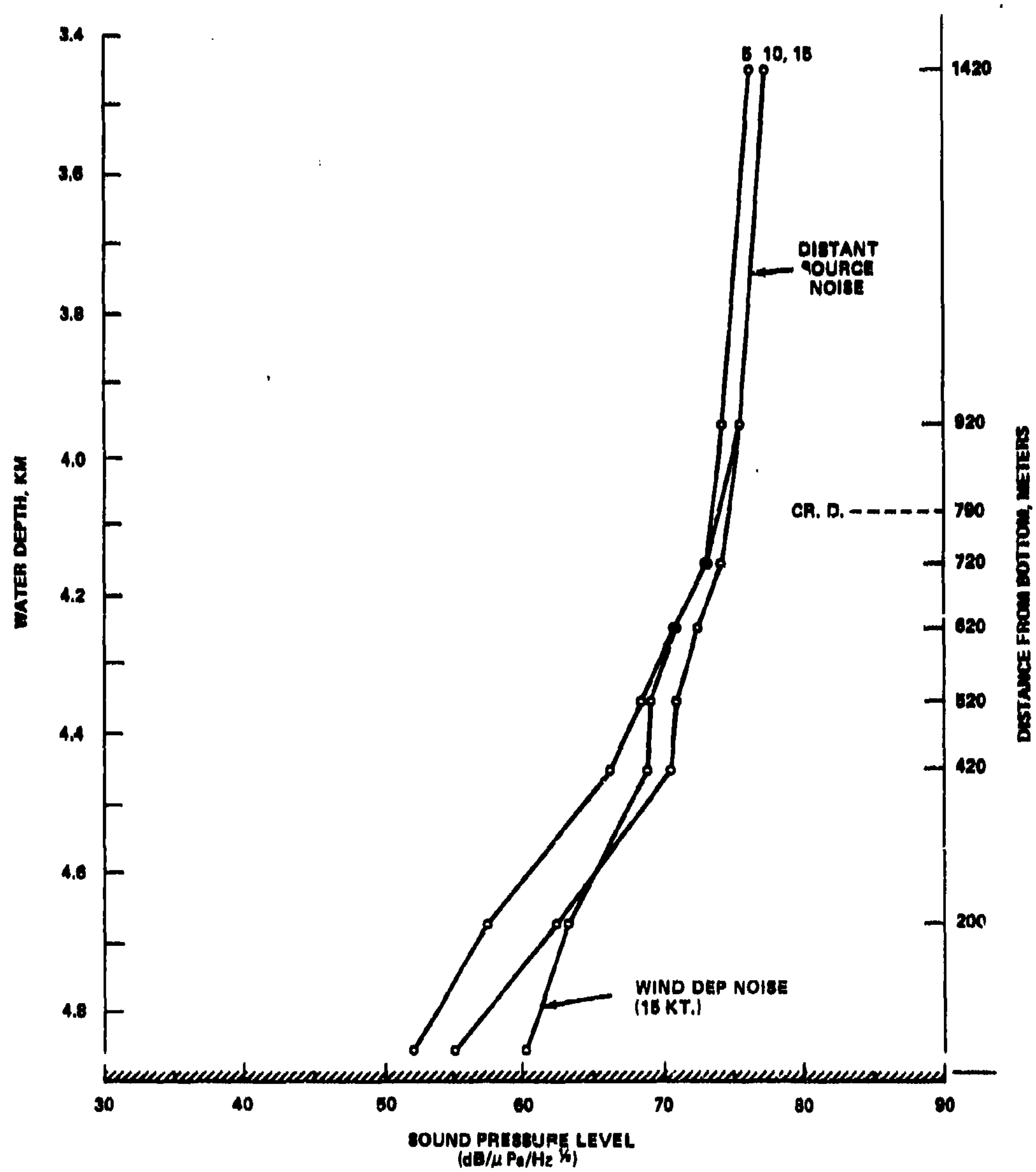

Figure 15(C). Ambient noise levels as a function of depth at 50 Hz for wind speeds of 5, 10, and 15 knots (U)

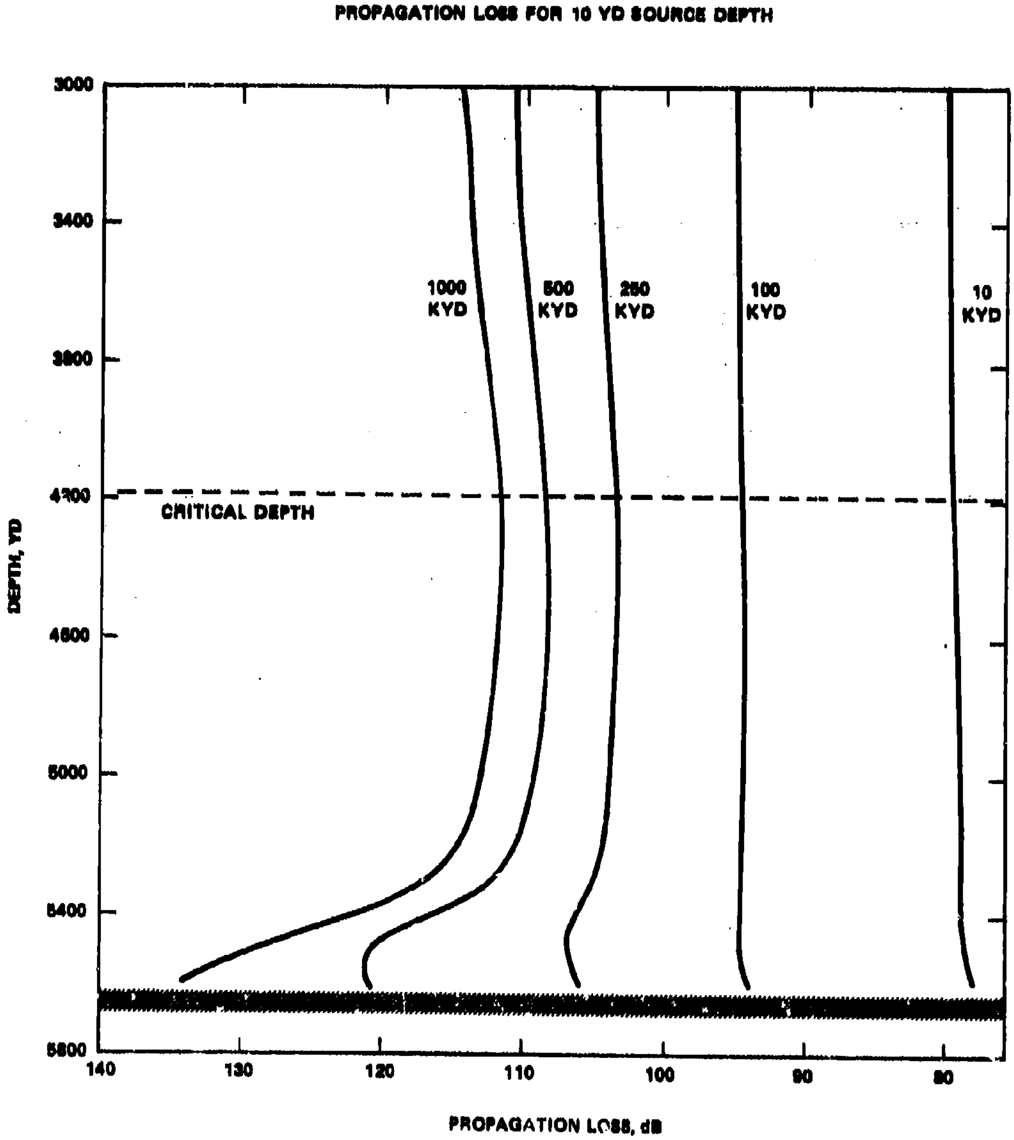

Figure 16(U). Propagation loss as a function of depth, with range to the source as a parameter for a source depth of 10 yards as calculated by Gordon (1974) using normal modes theory (U)

(C)
effect (for a single source) does not occur until the source-receiver separation exceeds about 150 miles. A similar effect is exhibited by the results of calculations using the FACT and the PE models (Anderson, 1976). Those results indicate a marked dependence of depth effect on the critical angle assumed for the bottom reflection process. All of the calculations suggest that depth excess relative to the conjugate source depth is probably a more significant parameter than depth excess relative to critical depth, where conjugate source depth is that depth at which the sound speed is again equal to that at source depth.

(C) Figure 17 displays an interesting example of the lack of depth effect, as is predicted in figure 16, for a source-receiver separation that is "not distant". Figure 17 depicts a situation in which a freighter (German, ADOLF LEONHARDT, bulk carrier, 22,000 tons, 10,500 brake horsepower) with a speed of advance of 15 knots is at its closest point of approach at a range of 100 miles. No significant bathymetric barriers exist between the ship and the receiver. The upper curve of figure 17 is from the 3960 meter hydrophone and the lower curve is from the 4850 meter hydrophone. Using the line structure of the lower curve, the corresponding lines can be identified in the upper curve. This implies that at a range of 100 miles no significant difference in propagation loss exists between the source and the upper and lower hydrophones.

(C) There is some evidence that bathymetry can alter the above observations significantly. The northern track, shown on figure 18, corresponds to the ship which produced the signature of figure 17. Twelve hours later, another freighter (Tiawanese, JINGUNING, general cargo, 9,800 tons, 1200 brake horsepower) with a speed of advance of 18 knots reached its closest point of approach at a range of 100 miles to the southwest of the site, as shown in the figure. No evidence of its signature can be found. An examination of figure 18 indicates that the bathymetry about

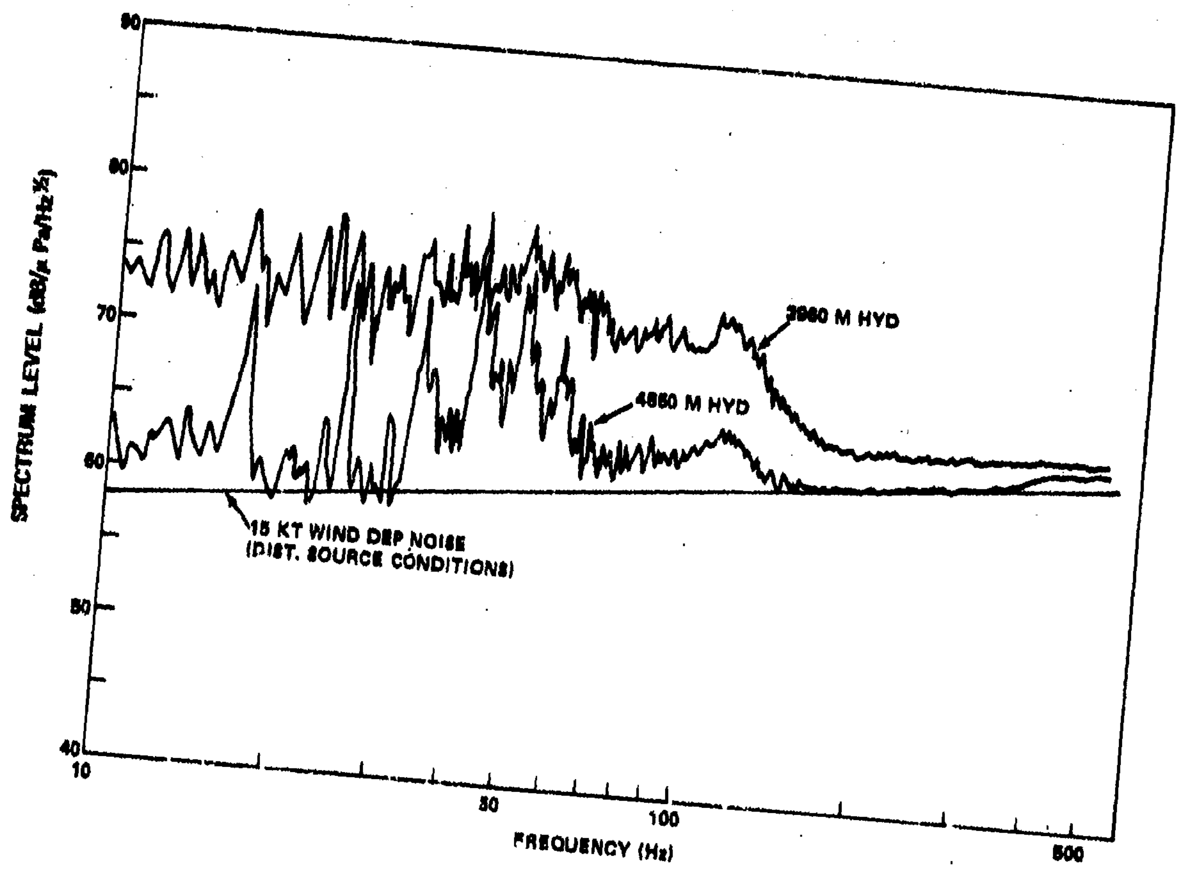

Figure 17(C). Spectra as measured with the 3960 meter (upper curve) and the 4850 meter (lower curve) hydrophones at the closest point of approach of a freighter (German, ADOLF LEONHARDT, bulk carrier, 22,000 tons, 10,600 bhp, 15 knots) 100 miles from the receivers, illustrating the lack of a significant depth effect for a "not distant" source. Local wind speed is 15 knots (U)

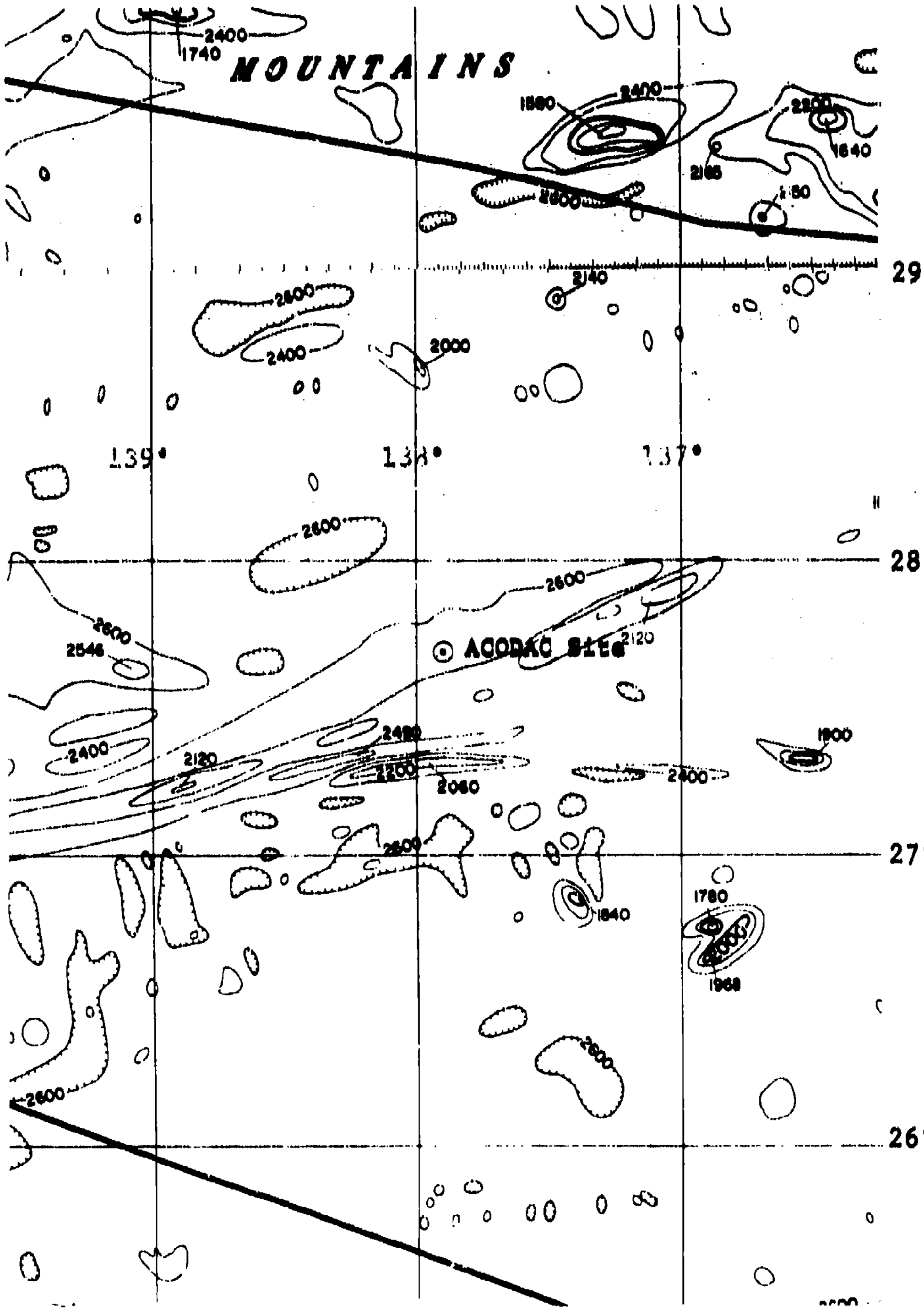

Figure 18(C). Bathymetry in the vicinity of the measurement site. The black lines are ship tracks discussed in text (U)

(C)
30 miles to the southwest of the receiving site could well be obstructing the propagation paths from this source. Bathymetric shielding effects have been observed by others (e.g., Morris, CAPER, unpublished results).

(C) Some further qualitative observations with respect to near bottom propagation can be made from figures 19 and 20. Figure 19 shows sound pressure level as a function of time for the indicated frequency as received on the 3960 meter hydrophone from a surface ship (Japanese, KANESHIZU MARU, bulk cargo carrier, 12,300 tons, 9,400 brake horsepower) which passed within 1 mile of the receiver site with a speed of advance of 15 knots. Figure 20 shows the corresponding output from the 4850 meter hydrophone. The two upper curves are displaced relative to the ordinate by 10 and 20 dB respectively.

(C) One interesting point is the asymmetry exhibited by the 26.1 Hz line near the CPA in figure 20 relative to figure 19. This asymmetry also exists for a 31 Hz line (not shown). Another interesting feature is the "dip" in the 44 Hz and the broadband level at 106 Hz in figure 20, which is not evident in figure 19. This is attributable to bottom reflection interference. Still another interesting feature is the sudden drop in level at a range from CPA of about 30 miles in figure 20. This is attributable to a 200 to 400 fathom ridge across the ship's path at 26 miles from CPA.

(C) Various attempts have been made to model the behavior shown in figures 19 and 20, using several different bottom types. The data, however, are not suitable for such analysis. From figure 19, the usable data from the 3960 meter hydrophone extends to only 36 miles, and this is too short a range to identify the effect of different bottom types (essentially, every type fits fairly well, including spherical spreading). For the data in figure 20, the drop in level at a range of 35 miles from CPA produces significant deviations from model results. The subject of propagation modeling to

(C)
near bottom receivers obviously requires considerable additional attention.

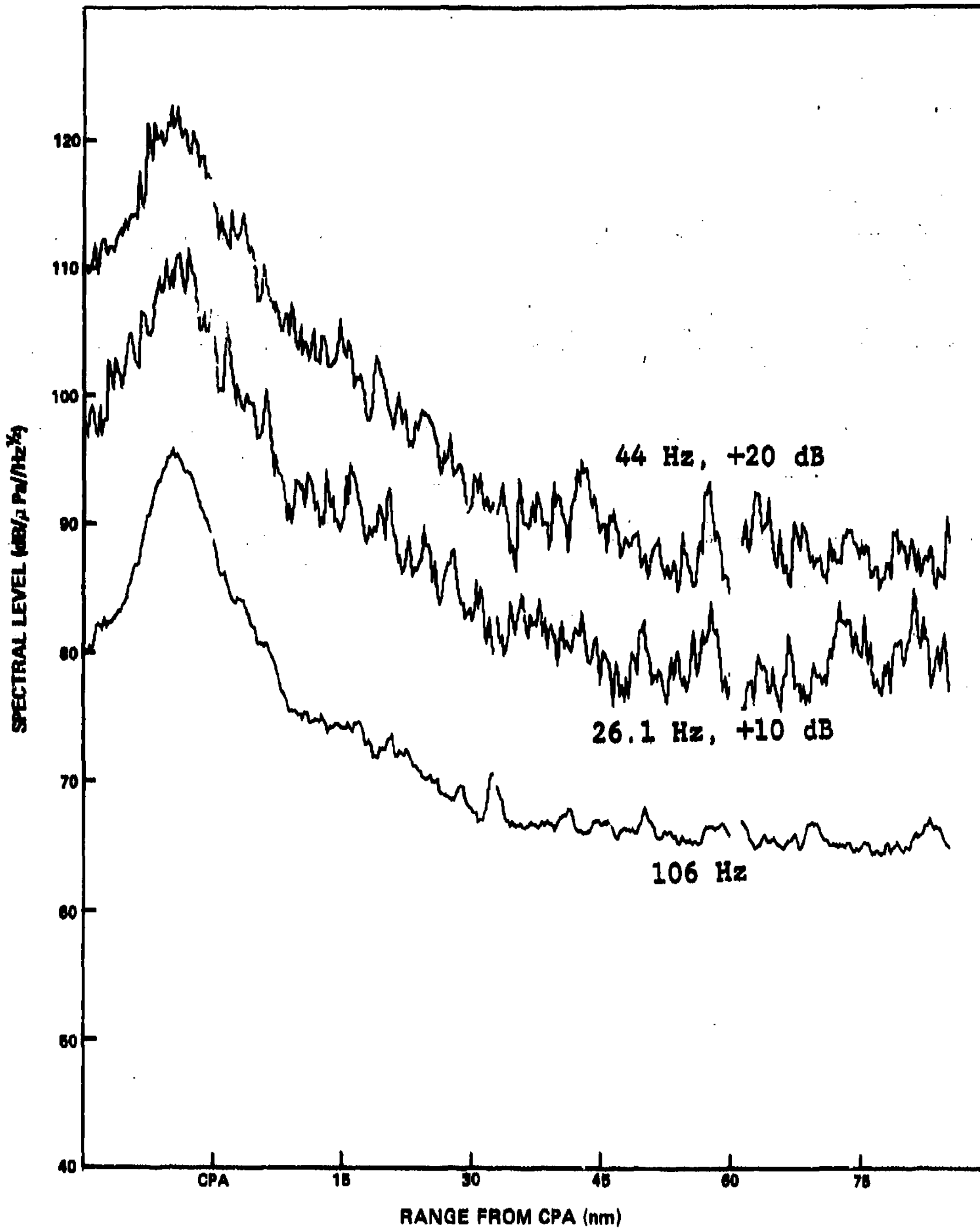

Figure 19(U). Received level as a function of range from the 3960 meter hydrophone for a freighter with a CPA of less than one mile. The curves labelled 26.1 and 44 Hz are lines. The curve labelled 106 Hz is the median sound pressure level in a 10 Hz band normalized to one Hz (U)

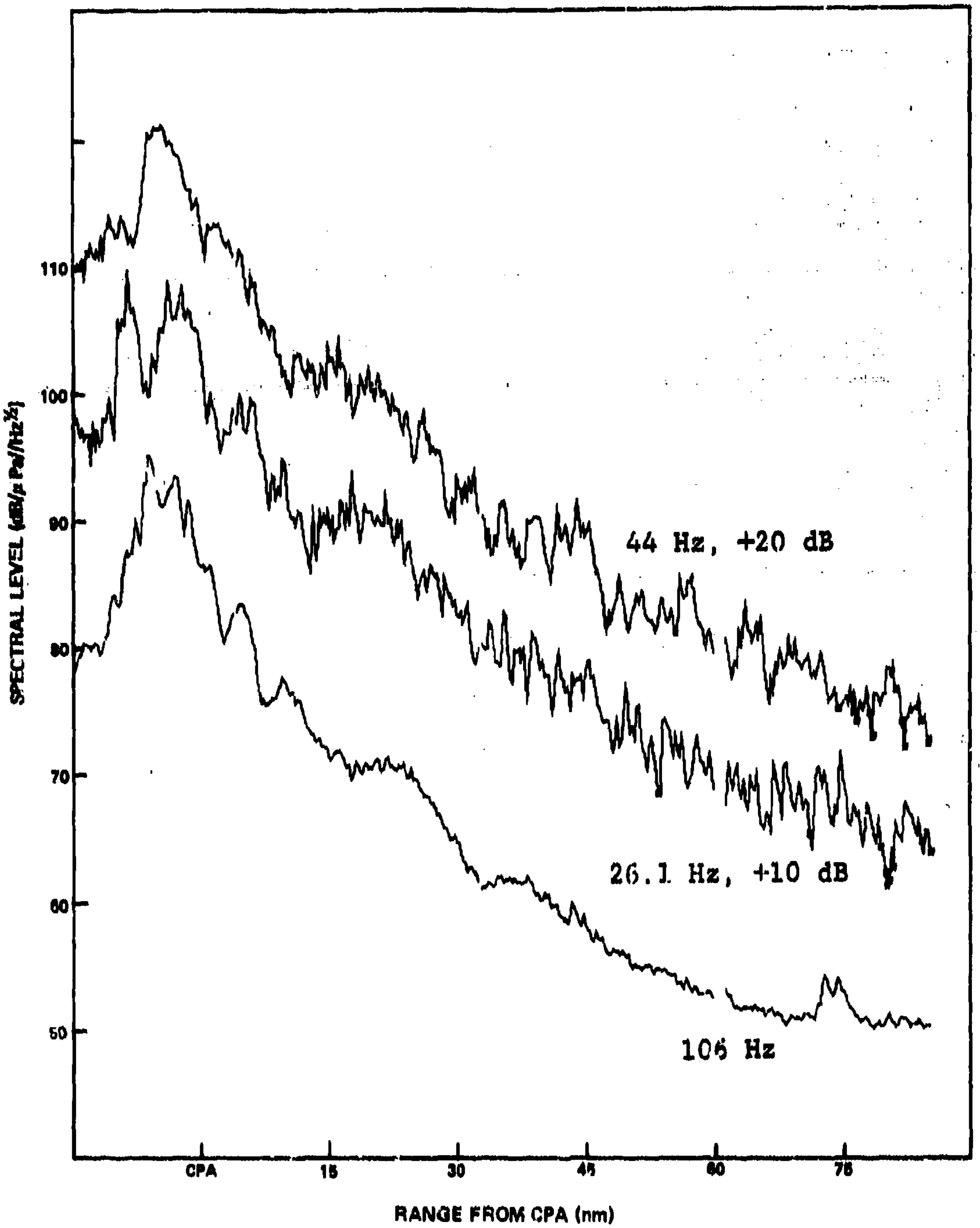

Figure 20(C). Received level as a function of range from the 4850 meter hydrophone for a freighter with a CPA of less than one mile. The curves labelled 26.1 and 44 Hz are lines. The curve labelled 106 Hz is the median sound pressure level in a 10 Hz band normalized to one Hz (U)

5.(U) SHIP SIGNATURES (U)

(U) During the course of the measurements, several uncontaminated ship signatures were recorded. Because of a continuing interest in such data, four of these signatures are shown in figures 21, 22, 23 and 24 when each ship was at its closest point of approach.

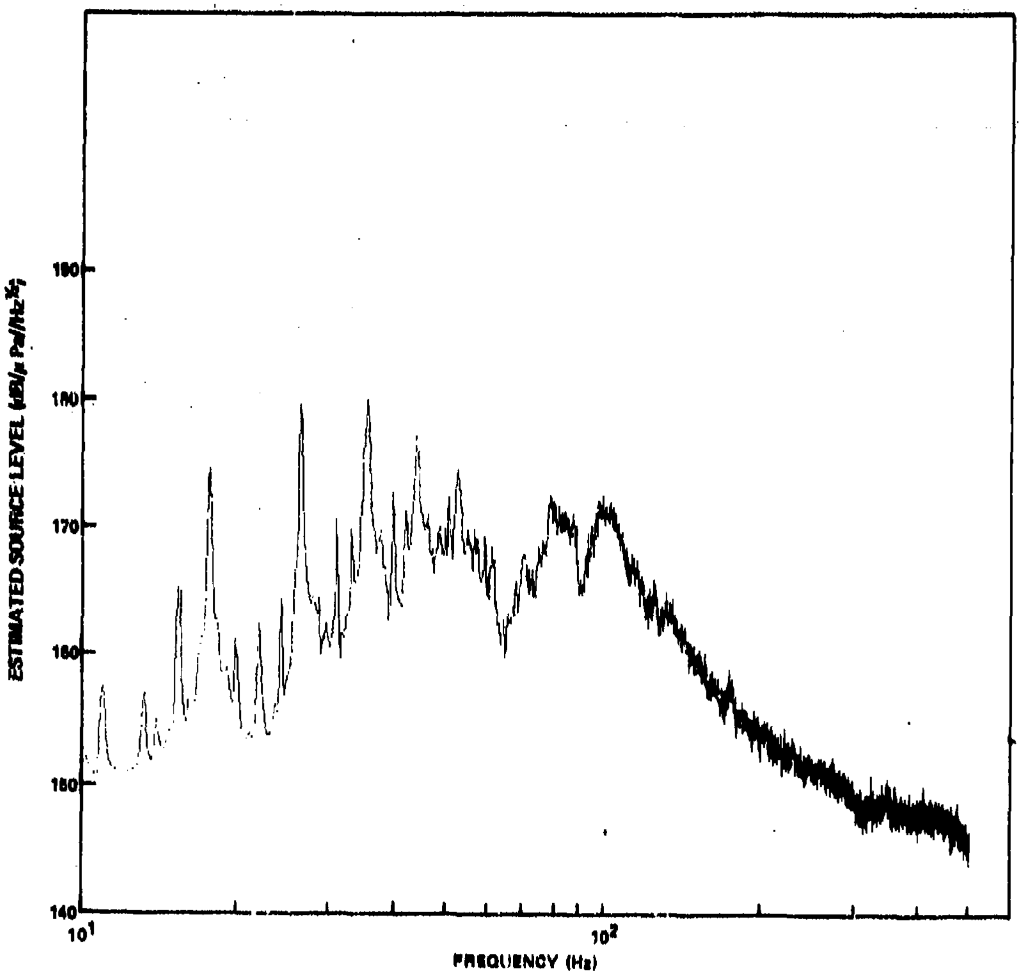

Figure 21(U). Estimated source level as a function of frequency for a Japanese bulk carrier (KANESHIZEK MARU, 12,272 tons, 9400 brake horsepower, 14.75 knots) (U)

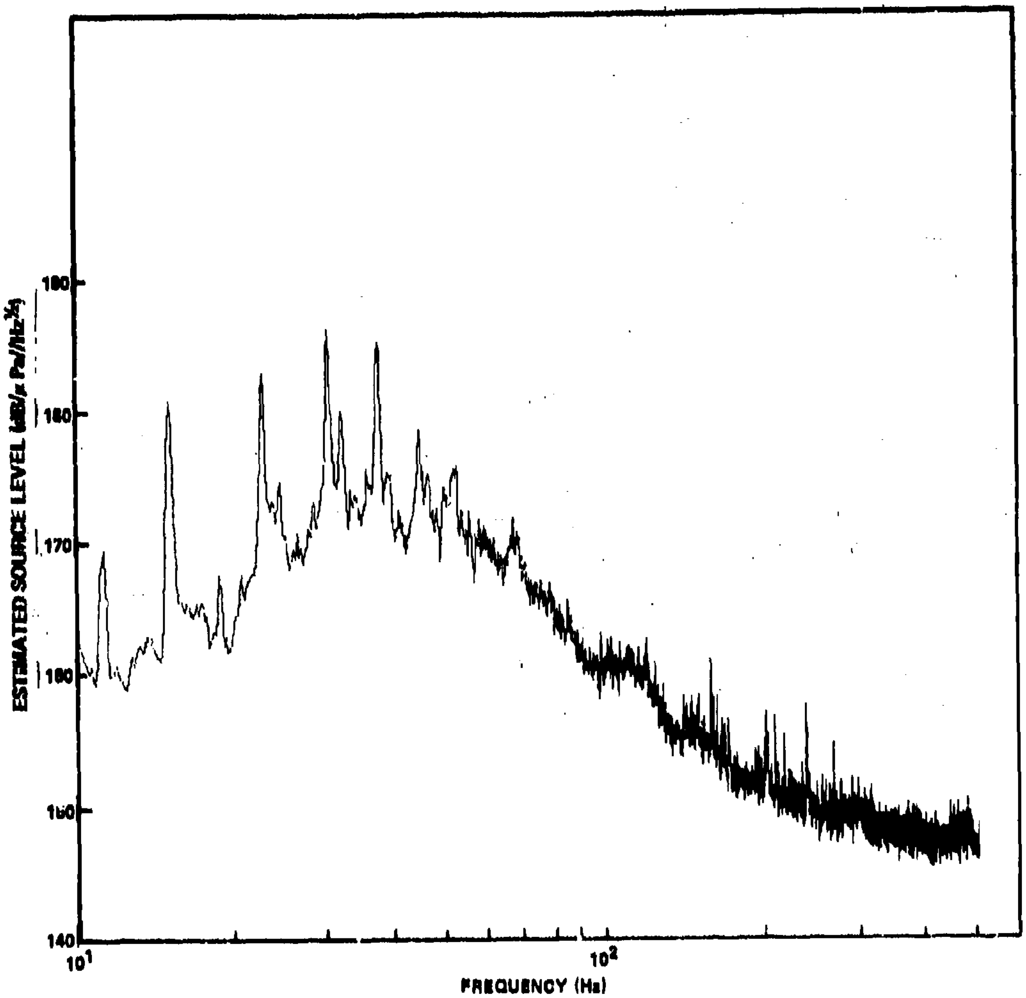

Figure 22(U). Estimated source level as a function of frequency for a Swedish refrigerator ship (ARAWAK, 8000 tons, 10,000 brake horsepower, 19 knots) (U)

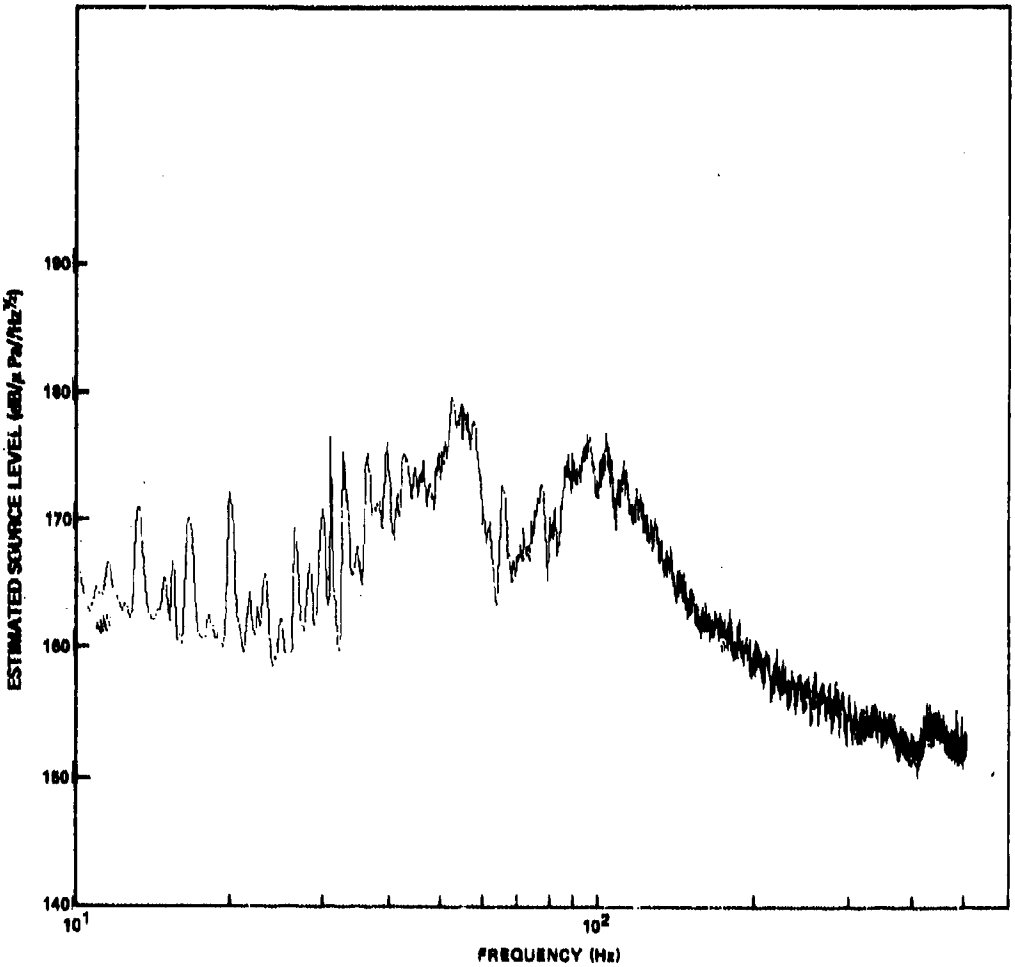

Figure 23(U). Estimated source level as a function of frequency for a Netherlands general cargo carrier (WONORATO, 7512 tons, 8250 brake horsepower, 16 knots) (U)

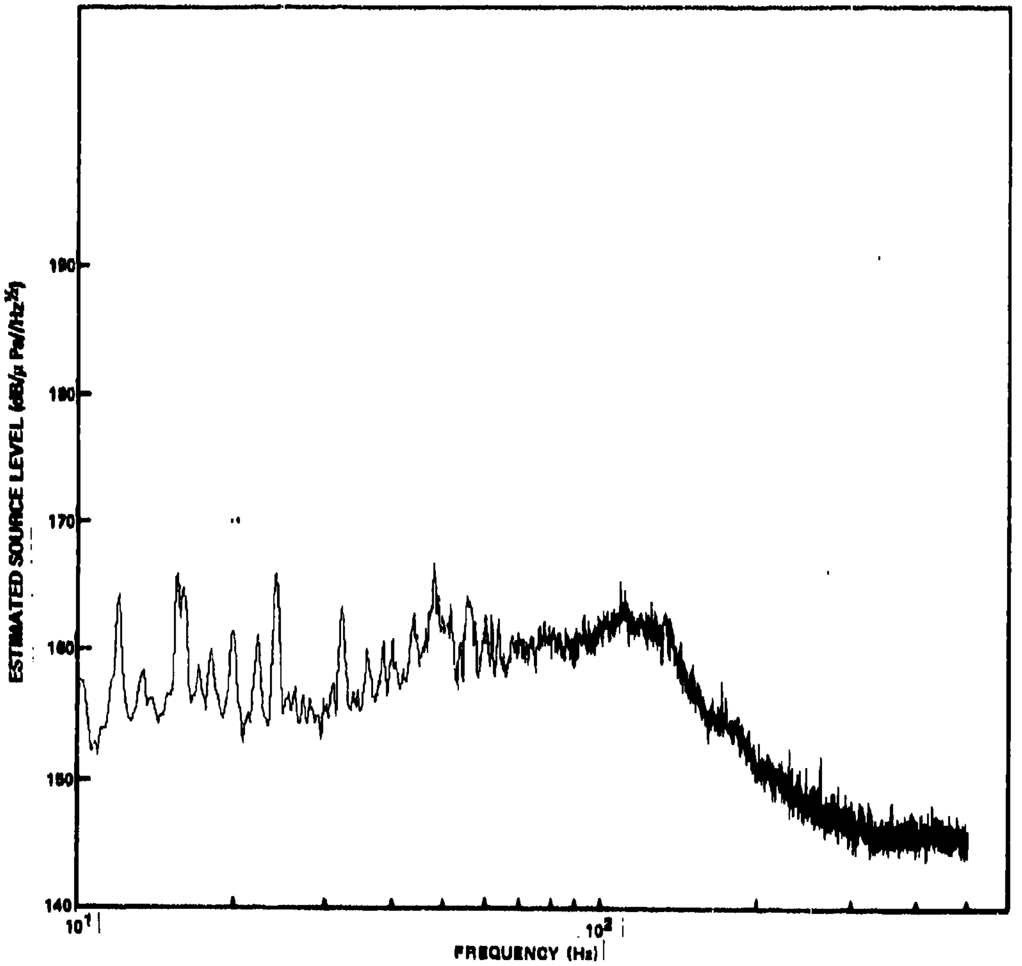

Figure 24(U). Estimated source level as a function of frequency for a Panamanian dry cargo carrier (GREAT SUCCESS, 7522 tons, 8400 brake horsepower, 11 knots) (U)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report gives preliminary results of ACODAC measurements made during CHURCH OPAL exercise, sponsored by LRAPP. Wind generated ambient noise spectra are presented as a function of wind speed over a frequency range of 10 to 500 Hz. The variation of ambient noise generated by distant shipping as a function of depth at the measurement site is given. A number of ship source level estimates as a function of frequency are presented.

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